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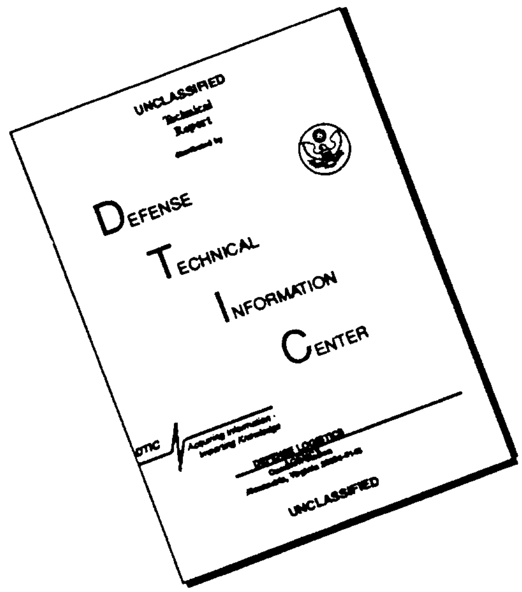

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Final Report
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Chemistry Division
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

IITRI Report C06538-1
TOTAL SYSTEM HAZARDS ANALYSIS FOR THE WESTERN AREA
DEMILITARIZATION FACILITY AT HAWTHORNE ARMY AMMUNITION PLANT
PRIORITY 1 - STEAM AND HYDRAULIC SYSTEMS
Volume 1, Summary Report and Appendices

Prepared by

Ronald Pape
Edmund Swider
Charles Heilker
Kim Mniszewski
Dwayne Eacret
Cindy Marrazzo

Prepared for

Hq. U. S. Army Armament Material Readiness Command
Rock Island, Illinois

July, 1982

FOREWORD

This is the first of three reports to be submitted under Contract No. DAAA09-51-C-3006 being conducted by IIT Research Institute, Chicago, Illinois, for the U. S. Army ARRCOM, Rock Island, Illinois. This report describes the results of a hazards analysis of the steam and hydraulic systems (Priority 1) at the Western Area Demilitarization Facility at Hawthorne, Nevada. The steam and hydraulic systems include the Washout/Steamout Building, the Refining Building, the Bulk Incinerator and the Process Water Treatment Plant. Reports to be submitted at a later date include hazards analyses of the mechanical demilitarization Systems (Priority 2 Report - Preparation Building, Mechanical Removal Building, and the Large Cells), and the incineration systems, the off-loading dock, and the driverless tractor system (Priority 3). The Priority 1 Report is submitted in two volumes, Volume 2 containing fault tree diagrams for the systems evaluated.

The primary IIT Research Institute project team consisted of Ronald Pape, Edmund Swider, Charles Heilker, Kim Mniszewski, Dwayne Eacret, and Cindy Marrazzo. In addition, Peter Milhalkanin provided part reliability data, and Daniel Lezotte and Harold Wakeley provided human error rates. Mr. Thomas Grady, a private consultant with considerable experience in explosive and propellant operations, helped scrutinize the results of the analysis.

Respectfully submitted
IIT RESEARCH INSTITUTE

Ronald Pape

Ronald Pape
Senior Engineer

APPROVED BY

Hyla Napadensky

Hyla Napadensky
Manager
Fire and Explosion Research

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1. INTRODUCTION

This report contains the results of a hazards analysis of the steam and hydraulic systems at the Western Area Demilitarization Facility (WADF) at Hawthorne, Nevada. The analyses have been divided into five plant areas:

1. Washout/Steamout Building North Tower
2. Washout/Steamout Building South Tower
3. Refining Building
4. Bulk Explosives Disposal Facility
5. Process Water Treatment Plant

The methodology used was a combination of failure modes and effects analysis (FMEA) and fault tree analysis (FTA), with quantification accomplished through the use of a fault tree computer model. These techniques are described in Section 2 of this report.

The hazards analysis that was conducted produced two types of results. First, the scenarios that can lead to a hazardous outcome were identified by constructing fault tree logic diagrams for each plant section. Such scenarios are chains of events or combinations of events that must occur together to cause the outcome of concern. For example, for an operator to become burned by touching a hot surface, several things must happen:

1. the surface must be sufficiently hot to burn someone, and
2. an operator must touch the hot surface

Both of these events are necessary in order for the operator to become burned. The combination of events is a scenario. To evaluate whether such a scenario is significant, "probability of occurrence" values are derived for each event in the scenario, thereby making it possible to compute the overall scenario probability of occurrence. Scenario probabilities are derived in terms of probability per year, or expected frequency of occurrence averaged over an extremely long time frame.

All the scenarios for the specific plant section are then compared based on their derived probabilities per year. Naturally, those scenarios with the highest probability values are most critical and must be addressed first.

It should be noted that the WADF operation is inherently hazardous in several respects. First, the energetic materials being processed are aged and likely to become contaminated. Experimental data on the effects of aging is limited, but the data that is available shows that aging and contaminants can drastically decrease the critical temperature for runaway reaction and can increase the sensitivity of materials to stimuli such as impact. This may be due to local inhibition of heat transfer or a catalytic effect.

In addition, many of the operations at WADF are labor intensive, and errors made by people are the most common cause of problems in process operations. Over the years, there will be considerable fixture modifications required to handle new materials or items. Each time there is such a change in the system, there is an opportunity for errors to be made creating new potential hazards.

The results of the analyses are summarized in Section 3 for each of the plant areas. The analysis was iterative in that conservative assumptions were used initially wherever possible, but these assumptions had to be refined for high probability scenarios to evaluate their credibility more realistically in the final answers. The major problem areas are thus presented in Section 3 with comments on their credibility and/or the major unknowns highlighted.

The appendices provide more detailed discussion in four areas. Appendix A presents the electrostatics hazard model used to evaluate the electrostatic discharge (ESD) scenarios. Appendix B provides the results of a survey of available compatability data conducted to help identify <u>types of problems</u> that can be expected at WADF, however, the compatability summary should neither be interpreted as complete nor used to identify the specific compatability problems that may be of concern at WADF. Appendix C discusses the rationale used to evaluate the potential for runaway reaction in liquid explosive holding vessels, such as melt kettles or the separator vessel in the Washout/Steamout North Tower. Runaway reaction was identified as the dominant hazard in the North Tower and the Refining Building. In Appendix D, a number of specific scenarios from the North Tower analysis are discussed and the basic event probabilities are provided for each component in the scenarios. These North Tower example cases are presented to provide the type of thought process used to derive the expected frequency of occurrence. Finally, Appendix E tabulates accident reports obtained from the DoD Explosives Safety Board Files. This table is provided to give the reader background on what types of incidents have occurred historically.

2. HAZARDS ANALYSIS APPROACH

In this section the hazards analysis approach used to evaluate the Priority 1 systems will be summarized. Basically, the following steps were used in the analyses:

a) Collect Available Information

b) Review Information/Learn System

c) Conduct a Failure Modes and Effects Analysis (FMEA)

d) Develop Fault Tree Logic Diagrams for System (FTA)

e) Quantify Fault Tree (derive scenario probabilities)

f) Interpret and Summarize the FTA Results

For the purposes of this program, the failure modes and effects analyses served to identify types of consequences and types of scenarios to be expected for different areas of the WADF. The FMEA's were used to learn the system and guide the development of the fault trees. Fault tree analysis was the primary methodology used to identify and quantify credible hazards at the facility. The FMEA and Fault Tree methods are described below:

2.1 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Modes and Effects Analysis is a relatively simple and direct approach for identifying basic sources of failure and their consequences. This method is not rigid and can be used for widely differing applications. It is especially applicable for identifying sources of malfunctions in hardware systems or in process equipment. The primary purpose of the analysis is to identify and remove failures that can cause hazards. However, as a side benefit, the analysis also leads to the identification of failures that are in themselves not hazardous but might affect the reliability of the functioning of a system. The results of such an analysis also may serve as an input to a Fault Tree Analysis, although more generally the two methods are used independently.

A Failure Modes and Effects Analysis is carried out by filling in a table having column headings such as the ones shown in Figure 1. This format is the one used for the Priority 1 systems. The first two columns list the

Systems/ Task	Component	Initial Failure	Chain of Events	Consequence

Figure 1 Failure Modes and Effects Analysis Format Used for Priority 1 Systems

system parts and procedure steps obtained from the available drawings, written descriptions, etc. The third column is used to identify the different possible failure modes for each entry listed in the previous columns. There may be several entries in column 3 for each system part or task. Given these initial failures, the possible chains of events were described in the next column, and the ultimate effect on the system was given in the last column. The Priority 1 FMEA tables were relatively formal and time consuming to produce. These tables were used primarily as "shopping lists" for fault tree development, a function not necessitating the formal presentation. In Priority 2 and 3 analyses a less formal FMEA presentation will be utilized, although this method will still be used to provide the basis for fault tree diagramming.

2.2 FAULT TREE ANALYSIS

A powerful method that has developed rapidly since 1962 is the Fault Tree Analysis. This method may be viewed as a systematic and comprehensive investigation of a postulated accident before it occurs. The term "accident" in this case is used to signify any kind of undesired event. The procedure is to define this undesired event and to identify all immediate causes that could have brought it about. These causes, in turn, are traced back through the system until one arrives at the ultimate causes that initiated the sequence of events that led to the undesired event. These ultimate causes may be failures of individual hardware components, or human errors, or other factors which either singly or in combination could have initiated the hazardous action.

An immediate result of such an analysis is a highly visible graphical representation of all basic failures and the paths whereby they can combine to create the undesired event. The method also can be used quantitatively. If data are available for the probability of occurrence of the basic failures, it is possible to calculate the probability of occurrence of the undesired event. In doing so it is also possible to identify those basic failures that are most critical, and the most critical sets of events (scenarios), so priorities can be established for taking corrective action.

An analysis begins by identifying an Undesired Event whose causes are to be traced. Graphically, this event is placed at the top of the page and represents the base of a tree whose branches are developed and extend downward. Once the undesired event, also called a Top Event is specified, it is necessary to identify the immediate causes which directly could cause this top event. Each of these causative events, in turn, is further broken down into subordinate events.

This process is continued until one arrives at basic input events that cannot be broken down further, or for which probability data are available so there is no need to go further. This process creates a diagram which resembles a tree whose branches extend and spread out downward, with each branch terminating in basic input events.

Figure 2 illustrates the diagrammatic arrangement of a fault tree, and Figure 3 identifies the geometric symbolism that is commonly used in fault tree construction. It is to be noted that a fault tree consists of three essential elements -- input events, logic gates, and output events. The basic logic gates are of two kinds, namely OR gates and AND gates. If an output event can be caused by one or more input events, either when each acts by itself, or when they act together, these input events pass through an OR gate. On the other hand, if an output event can be caused only when all input events must act in combination, these input events pass through an AND gate.

This concept is illustrated in Figure 4 where the top event is defined as the lighting of the light bulb. For the circuit diagram which shows all the switches arranged in series, all three must be closed for the light to stay lit. In the logic diagram for this arrangement, these three switches are shown connected to an AND gate. In the other circuit diagram, where the three switches are arranged in parallel, it is evident that the closing of any one switch would be sufficient to light the bulb. The logic diagram for this case shows the three input events to pass through an OR gate. If the probability for each of the switches A, B, and C remaining closed were known, it would be possible to determine the probability of the bulb remaining lit for each circuit. That is, the symbolic logic relationships can be converted to algebraic expressions for numerical calculation.

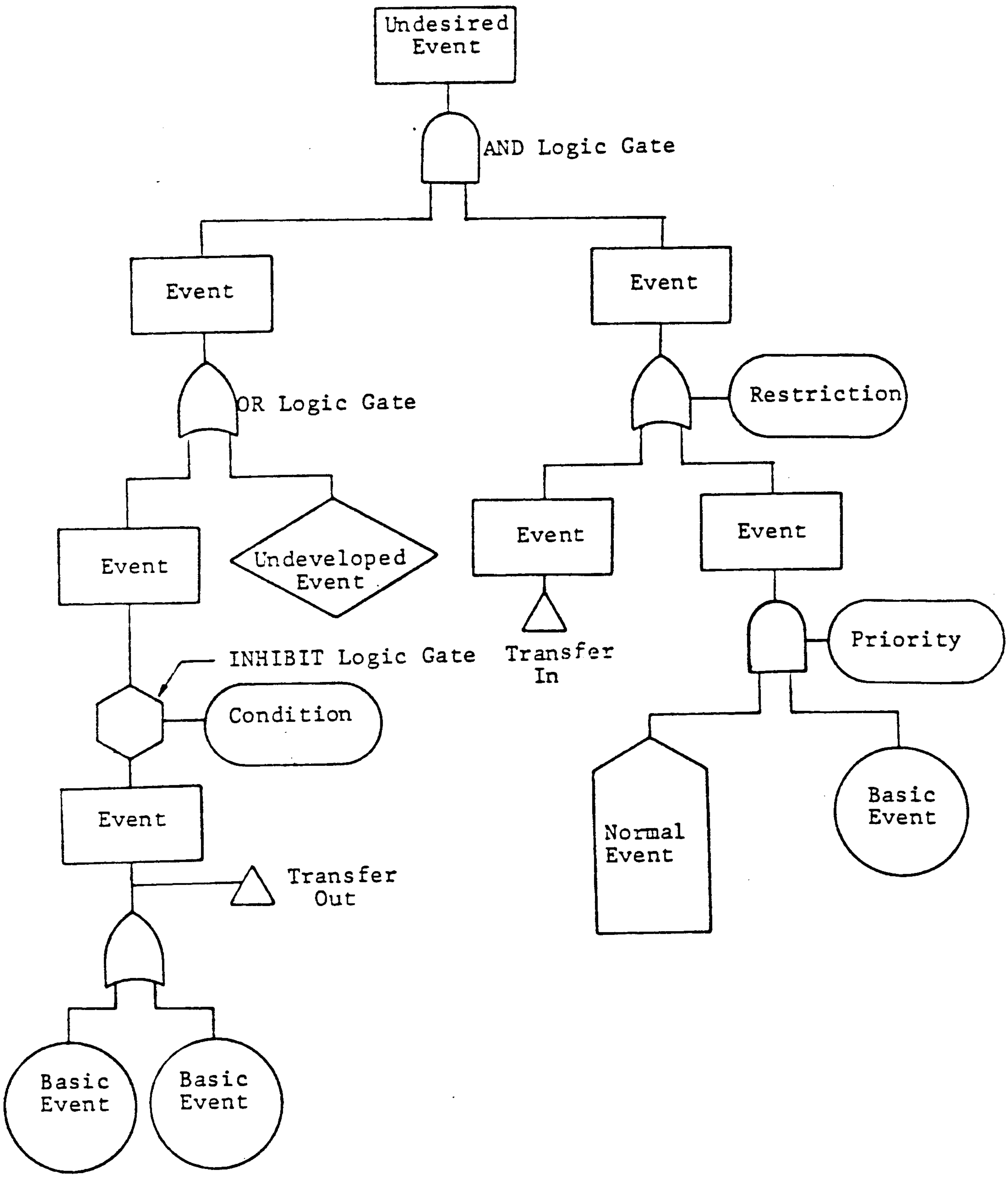

Figure 2 Diagramatic Arrangement of Fault Tree

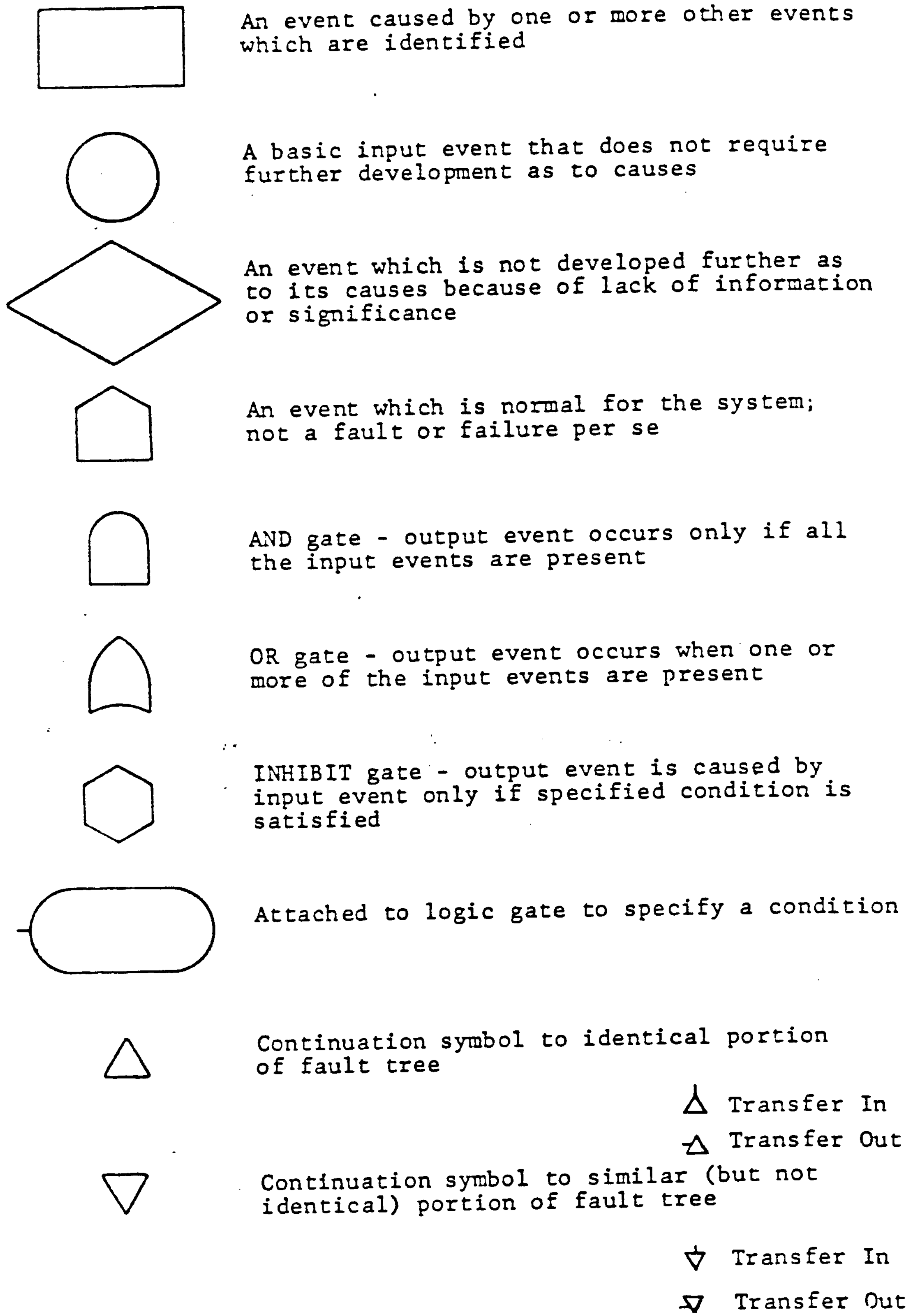

Figure 3 SYMBOLS USED IN FAULT TREE CONSTRUCTION

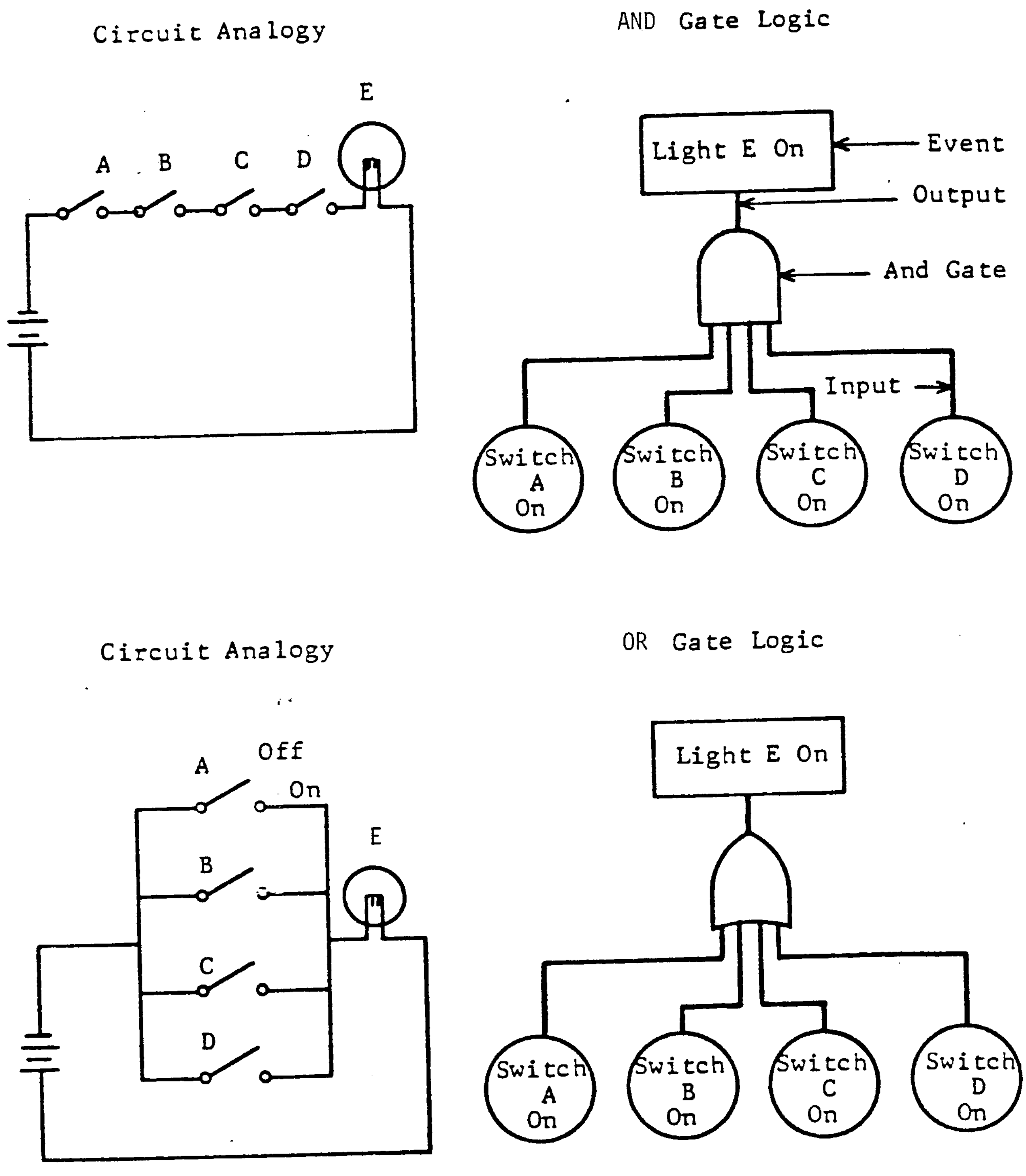

Figure 4 EXAMPLES OF USE OF AND AND OR GATES

2.3 QUANTIFICATION

IITRI has a fault tree analysis computer program for evaluating the fault tree diagrams. The first portion of the computer code uses a matrix approach known as the Boolean Indicated Cut Set (BIC) method to reduce the tree logic to a list of scenarios (cut sets) that "lead to" the undesired top event of the tree. These cut sets are the hazard scenarios that must be evaluated.

Each basic event on the fault tree must be provided a probability of occurrence or a failure frequency (with associated downtime) for quantification of the tree. Four types of data had to be compiled to quantify the trees:

1. System Scheduling Data
2. Part Reliabilities
3. Human Error Probabilities
4. Initiation Probabilities

Scheduling information was largely inferred from the Batelle Report (reference 1). Part reliability data has been compiled at IITRI during prior hazards and reliability analyses from numerous sources. The primary source of reliability data used, however, was a compilation of non-electronic parts data developed by the Reliability Analysis Center, an ITTRI organization in Rome, New York (reference 2). Human error data has been compiled under a recent project conducted by IITRI for the Chicago Transit Authority (reference 3) and that was the primary source for human error probabilities used. For initiation probabilities, the primary source of data was the Hercules Hazards Analyses for WADF presented in the Batelle report (reference 1). A variety of explosives or propellants can be handled at each plant area. Rather than considering all possible materials, the most sensitive material for which data was available was used to quantify each initiation stimulus type. In addition, there were numerous cases where data was unavailable and technical judgements had to be made. For example, the probability that a significant amount of explosive would remain in a vessel during maintenance operations or that a local initiation would propagate into the bulk of material present were not easily quantified. Therefore, technical judgements had to be used to establish probability values for the analysis.

The criteria for safety adequacy is stated in the contract as:

"The minimum acceptable level of risk for the operation and maintenance for the entire WADF complex and any subsystem is 97.5 percent probability with a 95 percent confidence level that a category 1 or 2* accident will not happen during 25 years of operation (40 hours per week)."

This translates to specifying that the hazard incident probability per year for the entire facility is less than or equal to 1/1000 with a 95 percent confidence level. The 95 percent confidence level criteria will be evaluated for the facility as a whole using the dominant cut sets derived for the different plant sections as the basis. Once the dominant cut sets for the facility as a whole have been identified using <u>average</u> failure frequencies and error probability values, Monte Carlo simulations will be run (on these dominant cut sets) to develop a distribution of failure frequencies for the WADF as a whole. The distribution created for the WADF will reflect uncertainties involved in predicting basic event frequency or probability values, for example due to variations in equipment, training of personnel, scheduling, etc. The 95 percent confidence level will then be determined using the derived distribution. These "total facility" results will be presented in the final report. For the mean time, a probability criteria of 1/10,000 will be used as a cutoff value instead of "1/1,000 with a 95 percent confidence level" in order to interpret the fault tree analysis results for each plant area.

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* Hazard categories are defined as follows:

Category 1 - Catastrophic. May cause death or system loss. System loss shall be defined as damage which results in the loss of 25 percent or more production capability and requires 30 days or more to repair.

Category 2 - Critical. May cause severe injury, severe occupational illness or major system damage. Major system damage shall be defined as that which results in more than 10 percent loss of production capability and requires more than 3 days to repair.

Category 3 - Marginal. May cause minor injury, occupational illness or minor system damage. Minor system damage shall be defined as that which results in 10 percent or less loss of production capability or requires 3 days or less to repair.

Category 4 - Negligible. Will not result in injury, occupational illness or system damage.

3. SUMMARY OF PRIORITY 1 HAZARDS ANALYSIS RESULTS

The fault tree logic diagrams that have been developed for the Priority 1 systems are voluminous and are, therefore, presented under separate cover, Volume 2 to this report. The logic diagram for each plant area segments the analysis into three parts (see Figure 5):

1. Major System Damage Occurs
2. Severe Injury or Death Occurs
3. Severe Occupational Illness Occurs

The initial quantitative results obtained for the plant areas were totally dominated by the second two categories (Injury and Illness), as would be expected. The "Major System Damage" category was really of primary interest, because this category includes the more catastrophic events such as massive explosions of vessels, but these scenarios were dominated by the many ways that personnel can become injured or ill at work. In addition, the injury and illness hazards are in many ways generic and can be grouped for the total facility. Therefore, it was decided to separate out the "Major System Damage" category and quantify that portion of the tree independently for each plant area. The essence of the results for injury and illness throughout the plant was obtained by quantifying the total Washout/Steamout Building South Tower fault tree. The injury and illness results are summarized in the paragraphs below.

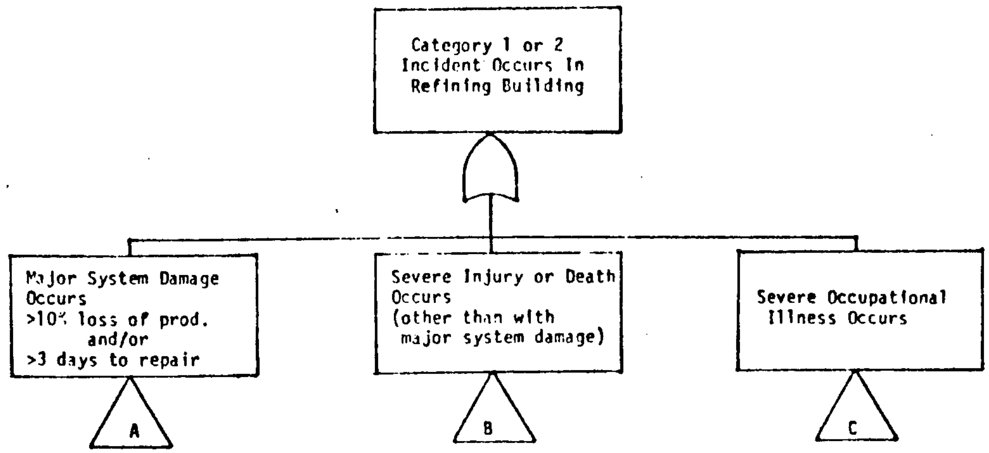

Fig. 5 - Typical Top Section of Fault Tree for a Plant Area

3.1 INJURIES AND OCCUPATIONAL ILLNESS

In the South Tower analysis, illness and injuries were estimated to occur with frequencies of 5.34 and 0.21 incidents per year, respectively. The estimated frequencies were based on conservative component probability values in all cases. Therefore, the compiled values should be considerably higher than will actually occur during operation of the facility. To quantify the probability of illness occurring given that an operator is exposed to a chemical, the toxic rating code presented in Reference 4 was used. The rating scheme in Reference 4 consists of the following format:

<u>Exposure</u>

Acute -------- single exposure of short duration (seconds, minutes, hours)

Chronic ------ prolonged or repeated exposure covering long duration (days, months, years)

<u>Effect</u>

Local -------- action takes place at point or area of contact (e.g. skin, mucous membranes of eyes, nose, etc.)

Systemic ----- site of action other than point of contact

<u>Toxic Ratings</u>

U = Unknown
0 = No toxicity
1 = Slight toxicity - produces only slight effects
2 = Moderate - not of such severity as to threaten life or produce permanent physical impairment
3 = Severe - severity to threaten life or cause permanent physical impairment or disfigurement

Thus, if the <u>acute</u> toxic rating was given as 3 for a material, the probability of "illness" occurring was assigned to be 1.0 for short duration exposures in the plant. If the <u>chronic</u> rating was given as 3, the probability of illness from a prolonged or repeated exposure in the plant was assigned a value of 1.0. Similarly, the probability of illness was assigned a value of 0.6 for toxic ratings of 2 and 0.3 for toxic ratings of 1 in order to discriminate between the cases.

It should be noted that the South Tower has a special toxicity problem in that explosive D will be handled. Explosive D is an extremely toxic material with ratings given in Reference 4 as follows:

Acute Local: Irritant 2; Allergen 2: <u>Ingestion 3</u>; <u>Inhalation 3</u>,

Acute Systemic: <u>Ingestion 3</u>; <u>Inhalation 3</u>.

Chronic Local: Allergen 2.

Chronic Systemic: Ingestion 3; Inhalation 3; Skin Absorption 3.

The potential injury and illness hazards identified from the fault tree analysis of the South Tower are summarized below:

ILLNESS FREQUENCIES

Scenario Description	Frequency (per year)
Contaminant Ingested	
• due to hand contact	3.24
• due to liquid splatter	1.50
• due to contaminant getting into food	0.015
Explosive Fumes Inhaled	
• due to Rotoclone belt slipping	0.014
• due to air handling duct dampers out of adjustment	0.55
• due to imbalance in air handling ducts from contaminant buildup on duct walls	0.011
• due to plugged eliminator plates in Rotoclone	0.0043
• due to plugged drain line in Rotoclone	0.0039
• due to plugged equalizing hose in Rotoclone	0.0039

INJURY FREQUENCIES

Scenario Description	Frequency (per year)
Fall on slippery floor during maintenance	12 0.0104
Fall on slippery floor - wet contaminant - during operation	0.0052
Impact due to mechanical assist control failure	0.0051
Impact due to washout turntable failure	0.0147
Impact due to mechanical assist part failure	0.0630
Lifting injury by lifting without mechanical assist	0.0255
Other injuries	0.0853 .2097

3.2 WASHOUT/STEAMOUT NORTH TOWER AND REFINING BUILDING

The North Tower of the Washout/Steamout Building and the Refining Building have many similarities. In the North Tower, explosive is steamed out of munitions items clamped to tilt tables using a steam lance. The explosive then drains into a separator vessel (a holding tank) and then is metered into melt kettles. In the melt kettles a vacuum is applied to the liquid for a prescribed period of time to remove moisture. The liquid explosive is then passed to a belt flaker, and finally the product is boxed and weighed. The asphalt liner and remaining explosive in the metal casing are steamed out in an autoclave. The autoclave products drain into a kernelling machine where they are solidified into small pieces by mixing with cold water. The product from the kernelling machine is transported to the Bulk Explosive Disposal Building for incineration.

In the Refining Building, the munitions items are placed in an autoclave in a fixture such that steam contacts only the outer surface of the items. Explosive then melts out and drains into melt kettles. No separate autoclaves or a kernelling machine are used to remove an asphalt liner, but the remainder of the system is almost identical to that in the North Tower.

Runaway Reaction

In both buildings, by far the most dominant category of scenarios involved runaway reactions in liquid explosive holding vessels - primarily in the melt kettles and separator vessel, but also in the North Tower autoclave if stratification of explosive and asphalt occurs in the bottom of the vessel.

A thermal runaway is a decomposition reaction in which the chemical involved (e.g. a melted explosive) generates heat more rapidly than it can be dissipated. This heat buildup results in a temperature rise in the area of decomposition. The temperature rise increases the decomposition rate, which generates more heat, which raises the temperature even faster, and so on. In this fashion, the temperature rise becomes extremely steep. The associated pressure also rises quickly and an explosion results.

The boundary (e.g. vessel wall) temperature at which the heat generated by the decomposition just equals the heat transfer rate, is known as the critical temperature. The critical temperature depends not only on the type of explosive present, but also on the geometry of the holding vessel, as the geometry affects the rate at which heat can be conducted away. Runaway reactions are possible only when the temperature of the explosive is above the critical temperature.

Pure explosives typically require temperatures well above their melting points and/or very long times for a thermal runaway to develop. Therefore, in order to have such an event in a facility such as WADF, the pure explosive must be modified in some way. Available experimental data show that some contaminants and aging (melt-remelt cycles) can substantially decrease the critical temperature and time to explosion. Many types of contaminants will appear locally within a chemical mixture, rather than homogeneously distributed throughout the mixture. Therefore, runaway reaction will develop locally in these cases based on the geometry of the contaminated zone (not the vessel geometry). In these cases, the runaway will be difficult to sense; one thermocouple is not likely to be at the correct location.

Agitation will serve to dilute these local contamination effects and improve heat transfer to the boundary of the vessel by convection. Agitation was not considered in the runaway reaction analyses that were conducted, although a series of trial calculations were conducted to determine if heat transfer would be enhanced significantly. It was concluded that the agitation effects on heat transfer is not dominant, particularly when considering the separator at 1 RPM and the autoclaves which have no agitation. Agitation effects on local contamination is considered to be more significant. In order to better understand the significance of agitation on the development of thermal runaways, it is recommended that simulation tests be conducted and more comprehensive prediction techniques be developed, including local contamination and agitation effects.

The fault tree analysis disclosed that several runaway reaction events could occur each year. Due to the lack of experimental data available to quantify this hazard, the analysis was conservative. IITRI strongly recommends that a comprehensive experimental program be accomplished in order to develop a better understanding of the effects of aging and contaminants and to obtain sufficient data to realistically quantify the potential for runaway reactions at WADF. The limited data available characterizing the behavior of contaminated and aged explosives show a significant increase in the susceptibility for thermal explosion. The rationale behind evaluating the runaway reaction hazard is presented in Appendix C.

The fault tree analysis indicates that prolonged holds due to system problems downstream of the hold vessel will be the major cause of thermal explosion in the melt kettles, separator, and North Tower Autoclaves. In the analysis prolonged holds were considered to occur within a single shift the majority of the time, with two hours beyond the normal operating time being most typical.

The next highest probability runaway reaction scenarios involved prolonged holds with explosive in the long drain line sections at the bottom of the melt kettles and separator. In these pipe sections there will be no agitation available even under normal conditions, so the thermal explosion model is more realistic in this case. Calculations were still conservative in that the drains are not steam jacketed and will actually experience a somewhat lower temperature than was assumed. However, this lack of steam jacketing increases the probability that a certain amount of explosive will experience melt-remelt cycling, in which the same explosive is melted and rehardens several times. Tests have shown that samples of explosive subjected to such cycling are more susceptable to thermal runaway than samples which are not cycled.

The effect of a contaminant entering a hold vessel was found to be somewhat lower probability merely because it is less likely that a "bad" contaminant will enter the system than that a prolonged hold will occur. If an incompatible material enters the system, the susceptibility of the liquid explosive to runaway reaction could be greatly enhanced, as discussed in Appendix C.

Since not enough is known about the susceptibility of the WADF explosives to runaway reaction, all precautions must be taken to assure that a runaway reaction can be prevented or terminated early enough. Unfortunately, the options that are now available may not be adequate or may be extremely expensive.

In the opinion of IITRI personnel, the best approach would have been to protect the vessels in the same manner that reactor vessels are protected in explosive manufacturing facilities. Reactor vessels (for example in TNT plants) generally have a large diameter drain pipe in the bottom, opening into a water filled trough or tank. This would allow the tank to be emptied quickly. In addition, the liquid would be cooled and spread into a thin layer. Although liquid explosive holding vessels are not generally thought to embody the same level of hazard as reactor vessels, the WADF explosives are not pure and could be much more susceptible to runaway reaction than materials normally encountered in melt kettles. Modification of the vessels at WADF to be able to quickly dump the contents would require major redesign and equipment alterations.

The existing protective system used in the liquid explosive holding vessels is a gentle top surface deluge. Such a system should be effective in preventing propagation of a reaction from another vessel, e.g. through the ventilation duct work; however, this deluge is not effective in preventing thermal explosion in the vessel itself. Runaway reactions will generally begin locally, beneath the surface of the liquid. A gentle top surface deluge will create a crust of solid explosive and protect the reaction below the surface, allowing it to continue.

In addition to the deluge system, the vessels are protected by a drain line that can "dump" the contents to casting pans. This drain is only 3 in. (7.62 cm) diameter and is not expected to respond quickly enough in the event of a runaway in most cases. A much larger diameter line would be required in order to dump quickly enough.

Some of the concepts that should be considered to reduce the possibility of a runaway reaction include the following:

- Shorten the dead space in the drain lines at the bottom of the hold vessels. This is a relatively simple fix for a problem that appears to be very credible. Expensive
- Sense for temperature excursions using thermocouples at several locations inside the vessel. More locations monitored will increase the chance of detecting the onset of the reaction.
- When a runaway is sensed, dump the contents to casting pans using the existing system. The dump will be too slow in some cases but may be sufficient in others. Personnel should clearly understand that the dump cannot be counted on and should know to take other precautions (e.g. clear the area).
- In spite of the apparent gas generation problem, high speed high volume nozzles oriented below the liquid surface to ~~produce swirl~~ should be considered further. If it is found ~~to be~~ effective, this solution could be adapted to the existing equipment with relative ease. FIRST YOU HAVE to sense it
- Finally, better agitation will help dissipate ~~local heat generation~~. Perhaps enhanced agitation could be initiated when local high temperature is sensed. This may be enough to dissipate ~~the~~ reaction or to slow it down. This concept should be evaluated further.

The concepts mentioned above (and any other concepts thought of) should be studied carefully to determine their feasibility and practicality.

The remaining dominant problem areas identified in the hazards analysis of the North Tower are discussed in Appendix D. The fault tree for the Refining Building identified a parallel set of dominant potential hazards, and the evaluation of these hazards was nearly identical to that for the North Tower. These potential hazards are summarized below:

Lance Impact Initiation from Rough Handling During Steamout

See preliminary report for "Distracted" operator scenario

It was estimated that a lance operator could initiate explosive inside an item by impact (rough handling) at a probability (expected frequency) of about 5 X 10^{-3}/year. That is, initiation would occur by the operator forcefully pushing or swinging the metal tipped lance into protrusions inside an item, impacting liquid explosive coating the metal surfaces. This scenario could be avoided by using plastic tipped lances. The plastic introduces a possible electrostatics (ESD) hazard. This proposed modification should be evaluated further to assure that the ESD hazard imposed by a plastic tipped lance would indeed be negligible.

IITRI has developed a method for predicting the spark energies associated with dielectric surfaces including the flow of charges along the surface toward the discharge region, however, no experimental data exists for verifying this method or determining input parameter values. It is, therefore, recommended that experiments be conducted to measure spark energies for scenarios of this type.

Impeller Impacts/Friction Within Melt Kettle or Separator Vessel

If the impeller becomes misaligned during major maintenance or due to part failure, or if a foreign piece of metal enters the vessel, metal-metal friction and/or impact initiation could be possible within a melt kettle or the separator vessel. It was estimated that such an event could occur with a frequency of 2.22 X 10^{-3}/year. To better evaluate this potential hazard, it is suggested that tests be conducted simulating the frictional and impact simuli that would be experienced inside a melt kettle and separator vessel, if the impeller becomes misaligned or if a foreign piece of metal enters the system. Clearly, any major maintenance should include checks to assure that the impeller remains aligned after the vessel has been reassembled. Frequent inspections of the screen leading into the separator in the North Tower should be accomplished to assure its integrity.

Tool Dropped Into Melt Kettle or Separator During Major Maintenance

It was estimated that an operator will initiate a fire or explosion by dropping a tool into a melt kettle or separator during major maintenance with a frequency of 2.17 X 10^{-4} to 2.17 X 10^{-3}/year. This hazard can be minimized by attaching tools to the operator with a short cord so that the tool's fall is broken in most cases. In addition, strict management controls should be incorporated whenever major maintenance is to be accomplished. This would include use of area entry and hot work permit programs, and tool inventory controls.

Rotoclone Fire

Fires in the dust collection system were estimated to occur with a frequency of 2.17 X 10^{-3}/year. The major problem area is initiation of explosive dust deposited on the walls of ducts leading to the scrubber. Initiation could occur during cleanup/maintenance due to an operator dropping a tool or due to ESD from a person. Strict management controls (as discussed above) will serve to minimize the possibility of initiation in these cases. Initiation due to mechanical failure downstream of the scrubber (e.g. due to an overheated bearing) is expected to occur much less frequently because explosive dust will only collect on walls downstream of the scrubber if the scrubber operates inefficiently for a long time without cleanup.

Rough Handling of Separator Dipstick

It is quite likely that explosive will collect on the dipstick holder. Impacts of the dipstick onto its holder could occur by numerous scenarios. For example, if the operator misses the hole while hurriedly trying to insert the dipstick, a localized impact will result. If the explosive severely contaminates the holder it is possible that the dipstick could freeze in place and the operator try to knock it loose. It was estimated that initiation of explosive inside the separator vessel would occur at a rate of 1.82 X 10^{-3}/year by this means.

It should be noted that perhaps a worse problem with the dipstick is the potential for introducing contaminants into the system, increasing the potential for runaway reaction.

Item Impact Scenarios

Several scenarios were identified resulting in the explosion of a full munitions item due to impact. These include impacts during jib crane, building crane, and forklift manuevers (i.e. item moved into an obstacle or dropped). The probability of such an event was estimated to be 8.51 X 10^{-4}/year. The probability of initiation was based on incidents that occurred during the Vietnam war, therefore, this hazard is considered to be credible.

Person ESD

There are a number of locations within the WADF facility where explosive or propellant may be exposed and could be ignited by an electrostatic discharge (ESD) from a person, if the spark has sufficient energy. One such scenario has already been mentioned in the discussion of the Rotoclone duct work. It was estimated that initiation by ESD from a person could occur with a frequency of 8.12 X 10^{-4}/year for any given plant area where explosive is exposed. For the facility as a whole, this frequency will be about an order of magnitude higher.

Impingement of Viscous Explosive Onto Grate to Separator After Line Unblocks

This sceanrio is concerned with the sections of flexible hose between the tilt tables and the network of fixed pipes draining into the separator. These flexible hoses may have to be replaced periodically, either due to wear or in order to obtain the proper fit for a specific table tilt angle to be used. If the hose is too long, a dip in the line could result. Explosive will tend to stagnate at the low point, solidify near the wall and eventually block the flow, particularly with the more viscous materials such as H6 and HBX. If the solidified material suddenly breaks loose, it will eventually impact a wall of the pipe or the grate above the separator vessel. Liquid explosive wetting the surfaces of the solid piece or grate, could become ignited by the impact. It was estimated that this event has a probability of 7.66 X 10^{-4}/year. The credibility of this scenario and initiation mechanism should be evaluated further.

Impact of Separator or Melt Kettle Cover Onto Vessel Lip During Major Maintenance

It was estimated that an initiation by a vessel's cover knocking into the lip during removal of the cover could occur at a rate of 2.17 X 10^{-5}/year for any given melt kettle or separator. In this scenario, a significant quantity of explosive must be present inside the vessel at the time of the impact. Strict management controls, i.e. use of an area entry and hot work permit system, should effectively minimize the possibility that major maintenance would be accomplished without first thoroughly cleaning out the vessel.

Explosion Due to Foamup in Melt Kettle During Vacuum Treatment

Liquid Explosives have a tendency to foam, particularly when subjected to low pressure and agitation. If the foam reaches the port for the vacuum line in the cover of a melt kettle, it is conceivable that liquid explosive could get into the vacuum pump. The vacuum pump should not produce initiation sources as long as seal water is present. However, if the seal water is lost and the water pressure interlock fails, initiation may be possible within the pump. It was estimated that this event could occur at a rate of 8.8 X 10^{-7}/year. Vacuum traps in the lines from the melt kettles to the vacuum pump should be considered to prevent explosive from getting into the pump. The vacuum traps should be equipped with level switches to stop the vacuum pump and sound an alarm in the event that the level reaches a preset height.

ESD Scenarios

Several other electrostatic discharge scenarios showed up in the fault tree analysis as potential hazards. These are presented in Appendix D. However, after further analysis it was determined that the energy produced by these situations would be small, yielding very low probability of initiation.

3.3 WASHOUT/STEAMOUT BUILDING SOUTH TOWER

Results of the fault tree analysis of the South Tower Hydraulic Cleaning Operation indicate a category I or II accident frequency of 0.357 per year, excluding injuries and illnesses of various causes. This result can be further broken down as follows:

8×10^{-4} per year

- explosions (due to item impact or runaway reaction) - 0.00082 per year
- equipment damage incidents (mainly due to impacts) - 0.332 per year
- prolonged shutdown incidents due to yellow D plateout or other contamination problem -0.024 per year

$\frac{8}{2080} = \frac{2}{520} = \frac{1}{260}$

More detail on each of these categories is given below. It must be pointed out that fault tree input probabilities/frequencies for South Tower events are based on the assumption that an equal number of each item type must be processed in the long term. This, of course, results in much higher item production rates at the washout turntable operations than at the washout chamber, which is a realistic assumption. Also, it is assumed that yellow D process production is directly proportional to the number of item types containing yellow D. This results in yellow D operations occurring approximately 12/20 of the time with A-3 production during the remaining 8/20 of the time.

The most serious incidents considered are those involving explosion because of the higher potential of human and property losses. The fault tree analysis has shown that the most probable scenarios involving explosions are those resulting from impact of items during transfer operations. The most significant of these are described below.

Item Impact Initiation During Mechanical Assist Operations

Due to the high rate of mechanical assist device usage, the potential for mishandling incidents is greatest here. The table below gives one example of a scenario leading to an item impact initiation, involving operation failure (7×10^{-4}/year). Other similar but less likely scenarios involve mechanical assist brake failure and control system failure (1.92×10^{-5} and 5.61×10^{-5}/year respectively).

$240/1{,}000$ .004 4×10^{-7} per m.

Component*	Description	Probability/freq.
25	Projectile lifted with mechanical assist	61.2 items/hr
32	Operator releases item at inappropriate time	0.0005
26	Given mechanical assist failure, item impact results	0.5
28	Item impact causes explosive initiation	1.10×10^{-5}

Component*28 is the critical initiating event. Its probability is based on mishandling/impact incidents of bombs during the Vietnam conflict in the period 1968 - 1972. For 3 recorded explosion incidents, there were about $2.7 \times 10^{+5}$ mishandling incidents, derived from:

$$\left(\begin{array}{l}9{,}066{,}573 \text{ bombs produced} \\ \text{during this period}\end{array}\right)\left(\begin{array}{l}10 \text{ handlings/} \\ \text{bomb}\end{array}\right)\left(\begin{array}{l}3 \times 10^{-3} \text{ mishandlings/} \\ \text{handling}\end{array}\right) = \begin{array}{l}2.7 \times 10^{+5} \\ \text{mishandlings}\end{array}$$

This corresponds to 1.1×10^{-5} explosions/mishandling.

Item Impact During Washout Chamber Operations

Another somewhat similar scenario in the washout chamber is given in the following table (1.13×10^{-5}/year),

Component	Description	Probability/freq.
49	Item placed in washout chamber	0.99 items/hr
53	Operator control/mishandling failure	0.0005
50	Given washout chamber/operator failure item impact results	0.5
52	Given item impact, explosion occurs	1.1×10^{-5}

This scenario assumes the same probability of initiation due to impact as discussed above.

Equipment Damage Incidents

The potential for process shutdown due to equipment damage was shown to be much higher than that of explosion (about 0.332/year). This is due to wide variation of scenarios involving projectile mishandlings, equipment failures, etc. The scenario having the highest frequency of occurrence (1.03×10^{-1}/year), is equipment damage during washout chamber operations due to mishandling or

*Component numbers are those that appear on the fault tree diagrams in Volume 2 to this report.

equipment failure. This is primarily because of the high weight of projectiles processed in this area (260-2700 lbs). This problem area and the potential for initiation by item impacts indicate that operators using mechanical assist devices must be well trained, should be certified, and operation procedures must be strictly enforced.

Other Potential Hazards in the South Tower

Other incidents having a significant frequency of occurrence, resulting in a prolonged process shutdown include:

- loss of agitation in collection tank causes yellow D stratification, buildup or plateout (1.46×10^{-2}/year)
- various scenarios, involving the steam pressure dropping during the yellow D process, result in plateout (3.75×10^{-3}/year).
- yellow D process water heater thermostat fails, causing plateout problems (1.36×10^{-5}/year)

3.4 BULK EXPLOSIVES DISPOSAL BUILDING

Based on the results of the fault tree analysis, no scenarios were above 1×10^{-4} incidents per year; however, four problem areas emerged warranting further consideration:

1) Compatibility problems between explosives being processed
2) Flashback from an incinerator via explosive settled in the feed line
3) Impingement of large pieces of explosive within the grinder
4) Failure of grippers allowing a drum to drop during forklift manuevers or at the drum dumper

After subsequent evaluation, only the failure of drum grippers is considered to be a credible problem of significance.

Material Compatibility

In the bulk incinerator it would be operationally desirable to indiscriminately process whatever explosive materials require disposal at the time. However, mixing materials which are incompatible could induce a runaway reaction or produce sensitive compounds. With regard to the potential for runaway reaction within the bulk incinerator system, the materials present are at low temperatures and mixed with large quantities of water within the tanks and lines. Even if settling occurs, the temperatures should be well below critical values and runaway reaction is not expected to be a problem.

A survey of available compatibility data (see Appendix B) indicated that explosives are generally compatible with other explosives. This was to be expected since many explosive compositions have the same basic constituents. Only a few incompatibilities of this type were uncovered.

Explosive D with NC or (NC and NG) at 100°C
Explosive D with Haleite or Tetryl at 120°C
PBX 9407 with PETN
PBX 9404 with Nitroquanidine
Comp B and TNT with asphalt compounds (more a decomposition and quality control problem)

In addition, explosive D forms sensitive primary explosive compositions with metals. It should be noted that, the available compatibility data is always for pure chemicals. The WADF explosives are old; they may have experienced some decomposition and may contain contaminants that are not easily defined. Therefore, existing compatibility data may not be pertinent in many cases. Keeping these precautions in mind, it is suggested that a compatibility library be set up at WADF. Whenever a new material is to be disposed of in the bulk incinerator (or handled anywhere at the site) the existing data should be searched for potential problems. If the existing data base is insufficient to evaluate the new material, a battery of compatibility tests should be run on the material before the material is handled at the site.

Flashback from Incinerator

If explosives were allowed to settle out of the slurry suspension in the feed tank or feed line, a slug of material strongly concentrated with explosive, could be pumped directly into the incinerator. This could result in an explosion at the incinerator and possible flashback of the reaction for some distance in the feedlines.

Although this scenario is conceptually credible, the system design incorporates features which protect against the occurrence of such an event. First, the lines are automatically flushed with water at any shutdown. This would clear the lines of any explosive that could settle. Second, the feed tank is agitated for a period prior to pumping with the delay time automatically controlled. Third, the mixture within the feedline is circulated for a period (automatically controlled) before the pump to the incinerator can be started. At least two automatic controls would have to fail in order for a slug of concentrated slurry to be fed directly into an incinerator.

Impingement at Grinder

The grinder speed is 1200 rpm. Thus, at the periphery of the 0.5m diameter grinder cylinder the tangential velocity will be 31.4 m/s. As pieces of explosive enter the grinder, they will impact at about that relative speed.

Impingement data can be used to evaluate the potential for initiation. The lowest impingement velocity in the compiled sensitivity data at IITRI was for RDX (from reference 1) with a TIL* of 91.2 m/s for crude RDX from age tanks-

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*threshold initiation level

25 percent wet with the target plate at a 90° angle. This indicates that initiation would not occur. However, for large pieces of explosive dropped into the grinder, impingement data is probably not appropriate.

For large pieces of explosive, the surface layer will experience an impact stimulus of

$$e = \frac{1}{2} \frac{M}{A} V^2$$

where M is the mass of the piece, V is the relative velocity and A is the impact area. For HBX-1 the impact is about $1.6 \times 10^4 \frac{j}{m^2}$. This indicates that the ratio $(\frac{M}{A})$ must be greater than or equal to 32.5 Kg/m^2 for initiation to occur. If the explosive piece has a density of about 1.6 gm/cc, the following critical conditions for initiation are indicated:

Mass of Piece (gm)	Equivalent Diameter of Piece (cm)	Critical Diameter of Impact Area (cm)
9.4×10^{-4}	0.1	0.018
0.105	0.5	0.2
0.84	1.0	0.57
838	10.0	18.1

This table shows that the critical diameter required to achieve the TIL value for impact initiation is large compared to the piece diameter, particularly for the large pieces of explosive. Therefore, it will be nearly certain that the TIL value will be exceeded for large pieces. If the same set of calculations is done for the 50 percent probability of initiation level, essentially the same result is obtained. This indicates that initiaion would be very likely if no water were used during grinding. With water, initiation will be less likely and propagation from piece to piece would be prevented for small particle sizes. In fact for small particles, the impingement data would be more pertinent. However, if initiation occurs, the reaction of the piece itself could cause significant damage. Impact tests with wet explosive should be accomplished to determine whether this scenario is indeed credible. If large pieces are frequently fed into the grinder and the probability of initiation even with the water is high, this scenario could occur frequently. In fact, testing may show that such initiations are the "normal" operating condition for certain materials that are to be fed into the grinder.

Drum Dropped by Grippers

The three highest probability scenarios identified by the fault tree analysis all concerned grippers. Two were during fork lift maneuvers and the third involved the dumper grippers. It was assumed that 55 gallon drums 80 percent full are used to carry "dry" and/or slurried energetic material into the bulk incinerator building. The drums are transferred by forklift to the feed conveyer, by conveyer to the feed hopper, and then dumped into the hopper.

For forklift maneuvers, the operation frequency is estimated to be 9 batches of 6 containers per day, or 2.25 containers per hour. The forklift operator will improperly grip the containers 5 out of every 1,000 attempts (human error probability). It is judged that one out of every hundred of these errors will result in the drum slipping from the grippers and falling. When the drum slips from the grippers, it is likely that the cover will be pulled off also. The initial impact of the bottom of the drum is not likely to result in an initiation; perhaps an equivalent initiation probability to that from rough handling of bombs is appropriate for this initial impact (1.1×10^{-5} initiations per trial); however, if the drum then proceeds to catch on equipment, dump over, spill, and impact on its lip or side, initiation is much more likely. It is estimated that such a local impact could produce energies up to about 10^6 j/m^2. This would initiate dry explosive materials and the TIL for TNT solids settled/water wet is only 1.5×10^5 j/m^2. In such scenarios, the bulk of the material in the drum could easily be at the impact point allowing propogation to occur. It is judged that 1/10 of the drums that are dropped will tilt over and be initiated in this manner. It is also judged that most of the materials in the drums are nearly dry or moist, but are not primarily water. Then the estimated frequency for this scenario is given by:

$$f = \left(2.25\ \frac{\text{containers}}{\text{hour}}\right)\left(0.005\ \frac{\text{Set up errors}}{\text{Set up}}\right)\left(0.01\ \frac{\text{drum drop}}{\text{error}}\right) \times$$

$$\left(0.1\ \frac{\text{drums fall over}}{\text{drums dropped}}\right)\left(1\ \frac{\text{drums with slightly moist explosive}}{\text{all drums}}\right)$$

$$\left(1.0\ \frac{\text{ignition}}{\text{lip hit}}\right) = 1.125 \times 10^{-5}/\text{hour} = 4.7 \times 10^{-2}/\text{year}$$

In reality, the frequency may be less due to the cover possibly remaining intact, due to higher moisture contents in many of the drums, and due to some difficulty in having the ignition occur in the proximity of the bulk of the material present. Impact initiation data with wet explosives would be helpful in better quantifying this hazard. Very little data of this type now exists.

The other gripper failure scenario (at the dump hopper) is quite similar in all respects except that the grippers must fail mechanically (due to lost structural integrity). This will be much less likely to occur than where the operator in the corridor does not grip the drum properly.

It must be noted that forklift operations, because of the operator interface and the energy potential at the end of the tines/grippers, are notoriously hazardous. Potential for accidents resulting from forklift operations should never be underemphasized. Therefore, operator training, licensing, periodic retraining, and on-the-job testing, are strongly recommended.

3.5 PROCESS WATER TREATMENT PLANT

Credible hazards involving the water treatment facility are primarily confined to non-explosive injuries and toxic effects of explosives and chemicals. However, certain scenarios involving explosions emerged which, although marginal, cannot be ruled out entirely.

One scenario is concerned with a runaway reaction taking place in the coal sand filter during the steam phase of backwash cycle. The steam used is maintained at 15 psig, or approximately 120°C. Although exposure to steam at this temperature would not normally be considered dangerous, it has been found that the presence of certain contaminants may greatly reduce the critical temperature necessary for thermal explosion in explosive materials (see Appendix C).

One example of this phenomenon has been reported by Groothuizen, Lindeyer and Pasman (reference 10). Experiments conducted during an investigation of a remelt tank explosion showed that 100 gms of TNT, contaminated with cardboard fibers (from shell casings) and KNO_3, would self heat to ignition in an oven maintained at 135°C in a few hours. 100 gms of TNT contaminated with activated carbon ignited in an oven at the same temperature in as little as 15 minutes.

The authors hypothesize that these contaminants, rather than being chemically involved in the decomposition of TNT, exert their effect in two ways. First, the absorption of TNT by a solid having a large specific surface may enhance the rate of decomposition. Second, the solid when combined with insoluble decomposition products of TNT may form a dense slurry which prevents convective heat transfer, allowing local heating to occur. In support of this explanation, similar behavior was observed using samples of TNT contaminated with glass wool.

The point of this discussion is that we cannot be usre of the effect of anthracite coal, a high specific surface substance, on the critical temperature of the explosives to be processed at Hawthorne. From the pilot plant study, it is estimated that a layer of explosive 2 inches in thickness above the bed and penetrating 1 1/2 inches into the bed will be present in the filters prior to backwash. All ratios of contaminant to explosive will be represented somewhere in the penetrating layer.

Normally the steam phase of backwash lasts only for 5 minutes. It is not anticipated that this short exposure will cause any problems. The duration of backwash may be extended, however, due to mechanical failures or operator error. Should the steam phase of backwash last for, say 4 hours, the outcome is less clear. The water treatment facility is highly automated and checked periodically rather than monitored continuously. The filters backwash in sequence. Should one filter become "stuck" at some point in the backwash cycle, there are no obvious cues to inform the operator that something unusual is happening. It is likely that such an extended steam phase will go unnoticed.

Several failures can cause an extension of the steam phase of backwash. The cam timer which controls the sequence of steps could malfunction, or be set improperly. Loss of plant compressed air would prevent the operator of pneumatic cylinders from closing the flow of steam. The operator could valve off the compressed air supply by mistake.

A number of unknowns exist concerning this scenario. The coal may have no catalytic effect. The steam, which is injected roughly 30 inches below the top of the coal bed, may cool sufficiently before it reaches the explosive. Steam condensate or the latent liquid in the coal may act as enough of a heat buffer for any heat generated by decomposition. However, no data is available which conclusively rules out the possibility of such a scenario.

It is recommended that tests be conducted to determine the catalytic effect, if any, of anthracite coal on the decomposition of the explosives to be present at Hawthorne and to characterize such reactions in terms of critical temperature and time to explosion. In such an experimental investigation, it would be prudent to consider temperatures at least as low as summer environmental conditions. Test conditions should duplicate those actually present in the coal sand filter during backwash, as closely as possible.

Another scenario involving fire or explosion was the use of steel shovels rather than non-metal (e.g. wooden) ones for major cleanup in the sludge basin or trough, combined with cracks or fissures in the basin or trough. These fissures allow a degree of containment which enables relatively small amount of explosive to transition to detonation. It is recommended that only non-metal shovels be allowed in the area, and that the basin, sumps, troughs, and clarifier be regularly inspected for cracks. It is recommended that non-metal shovels be used in such facilities, if shovels are used at all.

More credible scenarios are available for toxic effects of explosives. One such scenario concerns explosive exposure during cleaning. If it is assumed that structures such as the flotator clarifier and backwash recovery tank will be cleaned periodically with a steam or steam-water spray, the person spraying will be exposed to a mist of fine water droplets, many contaminated with explosive. Explosive in such a form may be inhaled or absorbed through the skin. Even if masks and protective clothing are worn, leakage may be a problem. IITRI fault tree analysis indicates these problems are far more prevalent than the explosion than the explosion scenarios mentioned above.

Other scenarios appeared which are not exclusive to explosive treatment plants. Spillage or splashing of sulfuric acid or alum during pump or line maintenance were judged probable. A simple fall from the ladder on the carbon columns was also likely, owing to the lack of a safety cage and the frequency with which the ladder will be used (e.g. used in haste, with wet footing, etc.)

Another scenario concerned possible mixing of activated carbon with sulfuric acid, resulting in the release of highly toxic SO_2 fumes. Activated carbon will probably be present in the treatment room as replacement for carbon in the columns. Should it be stored near the sulfuric acid line or near the sulfuric acid pit, and a leak in the line occur, SO_2 fumes could be generated.

4. CONCLUSIONS AND RECOMMENDATIONS

In this section, recommendations scattered throughout this report and appendices have been consolidated. Additional suggestions, in the category of "good practices" are also included, although they did not necessarily emerge directly from the hazards analysis. The recommendations are listed below for each plant area covered under Priority 1:

North Tower and Refining Building

- It is strongly recommended that a comprehensive experimental program be conducted to evaluate the potential for thermal explosion in liquid explosive holding vessels with realistic contaminants and aged materials. Small scale tests of the types conducted at China Lake (reference 11) and in Holland (reference 10) may not be an adequate simulation of the conditions in the actual liquid explosive holding vessels at WADF, e.g. the tests may be too small, agitation effects are not considered, and localized contaminants are not considered. Therefore, it is recommended that several large scale simulation tests be conducted, with and without agitation, with uniform and localized contaminants, etc. in order to identify where the small scale tests are valid and how to interpret the test results in terms of the actual system conditions. For those conditions where small scale tests are valid, it is recommended that tests of the type conducted at China Lake or in Holland be conducted with relevant explosives and contaminants not previously tested. This will permit us to better map out problem areas.
- The existing system for protecting against thermal explosion in the liquid explosive holding vessels at WADF is not expected to provide adequate protection in the event of a runaway reaction. The options available for modifying the WADF system in this regard include use of an undersurface deluge with swirl, enhanced agitation upon sensing a temperature excursion, temperature sensing at several locations within the vessel, and incorporation of a large drain line for dumping the contents quickly. It is recommended that options such as these be evaluated further to determine the optimum approach. Selected specific recommendations in this regard are provided below.
- The onset of runaway is expected to be localized and a single thermocouple (such as in the existing WADF system) is not likely to be at the right place to achieve a quick response. In order to better sense the onset of a runaway reaction, the use of temperature sensors covering a variety of locations within the vessel should be considered. The more locations that are kept under observation, the better the chance that the event will

be sensed early. Therefore, it is recommended that an investigation be conducted to determine the optimum type, number, and locations of temperature sensors for achieving the earliest possible detection.

- In the event of a runaway reaction, dumping the contents of the vessel to pans using the existing system should be accomplished if no better alternative exists. Operators should be made aware that the dump may not be fast enough, and they should evacuate the area quickly. It is strongly recommended that a faster response (large drain) dumping system be evaluated for incorporation into the liquid explosive holding vessels at WADF. This might be accomplished by modifying the existing vessels or may require installation of a totally new system.

- It is recommended that the valves in the drain lines beneath the melt kettles and the separator be moved as close as possible to the vessel to eliminate the dead space in the pipes.

- It is recommended that the potential for initiation of liquid explosive inside a liquid explosive holding vessel due to impeller impacts/scraping against the vessel wall be experimentally evaluated by simulating the actual conditions in the vessel for this scenario.

- It is recommended that a plastic coating be considered on the separator dip stick. The plastic coating will reduce the potential for impact initiation but may increase the possibility of electrostatic discharge.

- It is recommended that a static device be designed to assure that the separator dip stick is automatically cleaned off prior to re-entry into the vessel.

- During major maintenance involving removal of melt kettle or separator covers, extreme care should be taken to assure that the impeller will not contact the vessel wall during operation.

- The screen in the line leading into the North Tower separator vessel should be checked periodically for structural integrity.

- The credibility should be evaluated for the scenario mentioned in Section 3 in which a piece of solid explosive forms in a low point in the drain hose between the tilt table to the separator vessel and breaks loose impacting the grate above the separator. The velocity achieved by the piece and the potential for initiation are uncertain. Simulation tests are recommended to better evaluate this potential hazard.

- It is recommended that a vacuum trap be put in the lines between the melt kettle and the vacuum pump, to minimize the possibility of liquid explosive getting into the pump.

- Prior to major maintenance on vessels in the facility, the vessels should be thoroughly drained and steamed out. Even if a film of explosive remains in the vessel, the potential exists for the film to "flash" and injure the maintenance personnel present.

- Throughout the North Tower and Refining Building, the piping and ledges present are a maze of collection points for explosive dust layers to develop. Cleanup is quite difficult. The major potential hazards are "flash" reactions that could injure personnel, as well as a possible "train" for the reaction to get to a larger quantity of material, elsewhere in the building, e.g. an open item. The best solution to this problem is frequent hosedown of all the equipment, piping, ledges, etc.

- Use of plastic tipped lances for steamout in the North Tower should be considered. A plastic tip would reduce the chance for impact initiation during steamout, but the potential for ESD should be evaluated before making such a change.

- Insulation on steam lines within these buildings could pose a contamination problem. If a crack develops in the shell and explosive dust builds up, a fire or explosion could eventually occur. This is a potential problem of major importance. Frequent inspections should be made of the insulation's condition.

Rotoclone Cleaners and Duct Work

- Air handling ducts should be inspected and cleaned frequently to avoid any significant buildup of an explosive dust layer inside the ducts. Periodically flushing out this system (e.g. with hot water) should be considered to minimize the buildup.

- The Rotoclone should be tested frequently to assure efficient operation. The inside walls of equipment and ducts downstream of the scrubber should be inspected to assure that a dust/residue layer is not developing.

South Tower

- Yellow D solubility in water is extremely sensitive to temperature. This results in a real potential for plateout of Yellow D within the south tower equipment requiring hazardous cleanup. Therefore, it is recommended that alternate methods of treating Yellow D be considered.

- Yellow D is an extremely toxic material. Great care must be exercised to protect operators from becoming exposed to this material. It should also be recognized that A-3 being processed in the South Tower can become contaminated with Yellow D if equipment is not thoroughly cleaned between operations. Personnel handling the A-3 may then be exposed to Yellow D without knowing it. It is recommended that an industrial hygenist specify appropriate protective clothing and breaking apparatus for workers in this area.

- Transport of Yellow D to the bulk incinerator is of concern. The transport containers apparently have been designed such that the temperature will remain sufficiently high during transport to avoid plate out. If an unanticipated delay occurs in transit (this is not that unlikely) Yellow D could plate out within the vessel. Redissolving the Yellow D before dumping the contents into the slurry tank at the bulk incinerator is likely to be a hazardous operation. It is recommended that emergency procedures be developed for this situation. Redesign of the vessel and planned burning or detonation of the vessel should be considered as options.

- The structural integrity of the floor grating within the South Tower should be evaluated to assure that the heavy items that are to be handled will not fall through the grating if an item is set down on the fourth level.

Bulk Explosives Disposal Building

- It is recommended that tests be conducted to simulate large chunks of explosive being put into the grinder. It should be determined whether such large pieces will ignite by impact in the grinder with and without water present. The consequences of such a reaction is also of concern - i.e. will the result be "fire cracker" type explosions or a more massive event with propagation between pieces of material? It is anticipated that the "fire cracker" type event will occur and possibly could damage the equipment.

- Assure that the hydraulic fluid being used has been evaluated for compatibility with the explosives and propellants to be processed - this really should be done for the total plant.

- Although great care is taken to prevent steel drums containing waste material from impacting each other in the bulk explosives disposal building, it is possible that drums can impact each other while stacked more closely enroute to the building. Care should be taken to assure the outsides of the drums are clean prior to transport and that the drums somehow be spaced on the cart to prevent drum to drum impact.

- At the metal detector feeding the grinder in the bulk explosives disposal building, if metal is detected it still could be carried into the grinder by residual water --- i.e. there is no positive action taken to prevent the metal from continuing downstream. Therefore, it is recommended that a side chute and/or automatic gate be incorporated at the metal detector to prevent metal from being carried into the grinder.

- When changing the grinder blades, the grinder wheel should not be rested on the floor grating, unless the structural integrity of the grating has first been evaluated to assure that the grinder will not fall through.

Process Water Treatment Plant

- It is recommended that tests be conducted to determine the catalytic effects, if any, of anthracite coal on the decomposition of explosives and mixtures of explosives present in the process water treatment plant.

- It is recommended that metal shovels not be used under any circumstances for cleaning the sumps at the process water treatment facility. Non-metal shovels, brushes and brooms, vacuuming, etc. are more desirable options that should be evaluated for this purpose.

- At Hawthorne, the process water treatment plant situation is different from that at other explosives plants. At Hawthorne, mixtures of a wide variety of propellants and explosives must be processed - not just a single material. As long as water is present in large quantities there should not be a problem. However, if water is drained from components and materials are allowed to dry during a shutdown, dry mixtures of energetic materials of unknown characteristics will be present. It is, therefore, recommended that components be kept flooded during such shutdowns.

General

- Every operation on every equipment item must be covered by a written procedure, reviewed and approved by operating and safety management personnel.

- A comprehensive training program should be required for all plant personnel, including information on potential hazards.

- All equipment operators should be given appropriate training courses and certified or licensed for operations in which they will be involved.

- All plant personnel should be tested for electrical grounding of footgear at least once a day with a sign-in sheet.

- Area surfaces should be kept wet during maintenance as part of the procedure.

- It is recommended that a 2 locker system be adopted for plant personnel. One locker should be for street clothes and a second locker for work clothes. All clothing should be changed at the beginning and end of the shift. Clothing should be supplied by the plant - nothing taken home. A shower should be taken enroute from taking off work clothes to putting on street clothes. This procedure will also help avoid street shoes being mistakenly worn in the plant areas.

- An area entry and hot work permit program should be set up to assure that all temporary repairs and maintenance operations are well thought out and accomplished with several levels of management checks.

- During maintenance, tools should be connected to the workmen by a cord to help break the fall of the tool if it is dropped.

- Strict cleanliness must be enforced at all times in the plant, particularly when personnel leave contaminated areas to go to lunch or at the end of the shift. Nothing should be eaten in the work area. No food should be allowed in the work area.

- A medical surveillance program should be set up to screen personnel for specific jobs at hiring and to assure that long term health damage is avoided.

- It is recommended that a compatibility data library be set up at WADF. Whenever a new material is to be handled anywhere at the site the existing data should be searched for potential problems. If the existing data base is insufficient to evaluate the new material, a battery of compatibility tests should be run on the material.

- Existing calculation methods for estimating the electrostatic discharge energy produced by a charged dielectric surface generally overestimate the spark energy in this type of ESD scenario. The actual spark energy cannot be calculated using such methods. IITRI has developed a simple model for estimating this spark energy from a dielectric surface. The model lacks the required input parameter values and validation. It is suggested that tests be conducted to provide these inputs and to validate the model. This will provide a much improved quantitative analysis method for ESD hazards associated with dielectric surfaces.

Final Note

Appendix E to this report is a compilation of incidents that have occurred in explosive and propellant operations in facilities in the United States. The appendix consists of short descriptions of the incidents grouped with regard to the type of process operation involved. The information was extracted from Department of Defense Explosives Safety Board Files under a prior contract conducted for ARRADCOM.

Although the process operations listed are not for demilitarization, many similarities exist. It is suggested that the table be scanned so that the reader obtains a sense for hazardous events that have occurred in the past. In reviewing hazards analyses, people generally are torn between concern for safety and non-belief of scenarios that do not appear credible. It must be remembered that facilities are never designed to include the obvious hazards. Hazards that remain are generally low probability, requiring several failures to occur. Yet, incidents do occur. It is the function of hazards analysis to minimize the likelihood of such things happening.

REFERENCE

1. "Final Report on a Study of Equipment, Processes, and Systems for a Demilitarization Facility at NAD, Hawthorne, Nevada, Phase II, Volume II", Battelle Columbus Laboratories

2. "Non-Electronic Part Reliability Notebook", DTIC Report ADA-A005-657, Jan 1975.

3. Wakeley, H. R. Pape, K. Mniszewski and S. Marèk, "CTA Rail System Safety Analysis" Vol. I Final Report

4. Sax, N.I., Dangerous Properties of Industrial Materials, 3rd edition, Van Nostrand Reinhold Company, New York, 1968.

5. Napadensky, H.S., and R. Pape,"Development of a Hazard Classification Procedure for Inprocess Propellant and Explosive Materials", Final Report ARRADCOM Contract DAAK10-78-C-0029, July 31, 1979.

6. Urbanski, T., Chemistry and Technology of Explosives, Vol. I, Pergamon Press Ltd., 1967.

7. Moore, A. D., Electrostatics and Its Applications, John Wiley & Sons, New York, 1973.

8. Cohn, E.M. and P.G. Guest, "Influence of Humidity Upon the Resistivity of Solid Dielectrics and Upon the Dissipation of Static Electricity", Bureau of Mines Information Circular 7286, June 1944.

9. Kolis, K., and R. Pietrzak, "Final Report - Investigation of Explosion Incidents, M117A1 750 lb G. P. Bomb", AMCPR-BR Tech. Report 117.

10. Groothurizer, T. M., E. W. Lindeijer, and H. J. Pisman, Explosivestoffe 5 (1970) 97.

11. Joyner, T. B., "Thermal Decomposition of Explosives", Parts 1-9, NWCTR4709, March 1969 - October 1973.

APPENDIX A

MODEL FOR EVALUATION OF ELECTROSTATICS HAZARDS

Model for Evaluation Electrostatics Hazards

Many of the electrostatics hazards considered can be viewed in terms of charging an equivalent capacitor. The circuit shown in Figure A1 is a reasonable model for many of these scenarios.

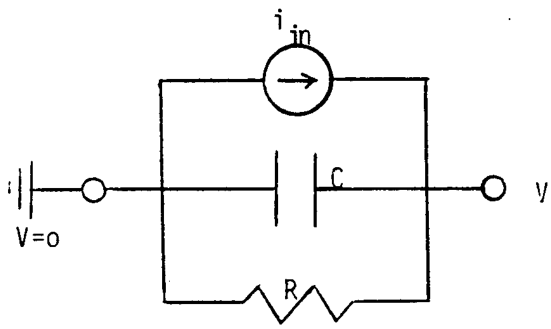


Figure A1 ESD Circuit Model

For example, the charge may be carried from one location to another by the flow of a powder between system components, a steam jet, or the shuffling of an operators ungrounded shoes. In each case, the rate of charge transfer can be viewed as a constant current power source, i_{in}. The components collecting or separating charge, have an equivalent capacitance C, and the charge can drain back to "ground" level through some resistance, R; in some cases R may be essentially an infinite resistance while in others R may be effectively a short circuit. For the circuit being considered the charge, Q, stored in the capacitor can be shown to increase by the following relation:

$$Q = i_{in} RC \left(1 - e^{-\frac{t}{Rc}}\right)$$

where t is time.

Thus, the maximum charge attainable is $Q_{max} = i_{in}RC$. The maximum voltage attainable is consequently:

$$Vmax = \frac{Q}{C} = i_{in}R$$

The energy associated with this voltage level is

$$e = \tfrac{1}{2} CV^2$$

and the characteristic time required to achieve this energy/voltage level is

$$\tau = RC$$

CHARGING RATE

To estimate the rate of charge transfer, i_{in}, the analyst estimates the mass flux $\dot{m}$ of charge carrier between the source and the target, and multiples this value by the average charge per unit mass of the carrier medium $\frac{Q}{M}$.

$$i_{in} = \dot{m} \left(\frac{Q}{M}\right)$$

for estimating the charge per unit mass the following information can be useful.

Max. Charge/Particle (Ref. A1)

$$Q = 3.3 \times 10^{-4} a^{-2} \text{ Coulombs} \left(\frac{Q}{M} \sim 0.2 \frac{\text{Coul}}{\text{Kg}} \text{ is typical for } 1\mu \text{ particles}\right)$$

where 'a' is the particle radius in meters

Water Sprayed By Means of Airblast (Ref. A1)

$$\frac{Q}{M} = 10^{-6} \frac{\text{Coul}}{\text{Kg}}$$

Liquids Such As Transformer Oil and Butyl Esters Disrupted To Form Droplets (Ref. A1)

$$\frac{Q}{M} = 5.23 \frac{\text{Coul}}{\text{Kg}}$$

Electrostatic Spraying Experiments With Octoil (diffusion pump oil)

2μ Particles (Ref. A1)

$$\frac{Q}{M} = 0.765 \frac{\text{Coul}}{\text{Kg}}$$

Coal Dust Suspension Charged By Impacts (Ref. A2)

mean particle size = 16μ

$$\frac{Q}{M} = 0.5 \text{ to } 2.3 \times 10^{-3} \frac{\text{Coul}}{\text{Kg}}$$

Electrostatically Active Powders Such As Starch and Cabosil (Ref. A3)

$$\frac{Q}{M} \sim 10^{-3} \frac{\text{Coul}}{\text{Kg}}$$

Water Mist Developed While Washing Out Ship Tanks (Ref. A4)

$$\frac{Q}{V} = 3.65 \times 10^{-8} \ \frac{\text{Coul}}{\text{M}^3}$$

estimated to be about

$$3.13 \times 10^{-8} \ \frac{\text{Coul}}{\text{Kg}}$$

"Charge Densities For Selected Process Materials As Determined In Controlled Chuting Experiments". Ref. A5)

Plastic Flake	7.1×10^{-7} Coul/Kg
Benzidine yellow	9.4×10^{-6} Coul/Kg
Gilsonite	2.6×10^{-6} Coul/Kg
TNT	2.1×10^{-7} Coul/Kg

CAPACITANCE

The capacitance, C, is the charge storage capacity per unit voltage of the component being considered. The capacitance is a function of the configuation of the component, and most real configurations are too complex to evaluate exactly. However, two simple configurations serve to characterize most situations of interest. These are the parallel plate capacitor and a spherical body at some distance above a grounded plane surface. The capacitance of most configurations can be estimated reasonably well by one of these models or some combination of spheres and parallel plate capacitors.

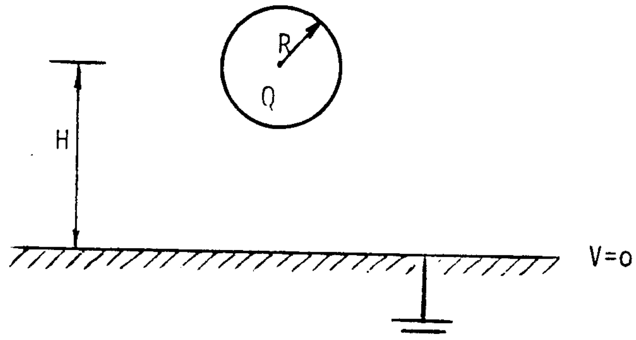
For a parallel plate capacitor, the capacitance is given by

$$C = \frac{\varepsilon_o k A}{\ell}$$

where ε_o is the permittivity of free space ($8.85 \times 10^{-12} \ \frac{\text{Coul}^2}{\text{nt-M}^2}$), k is the dielectric coefficient of the material separating the plates, A is the surface area, and ℓ is the separation distance.

For a sphere above a grounded plane (see Figure A2) the capacitance is given by

$$C = 2\pi\varepsilon_o R \frac{(2-\frac{R}{H})}{(1-\frac{R}{H})}$$



Fiqure A2 Sphere Above A Grounded Surface

As the ratio of R to H approaches 0 (i.e. sphere in space) the capacitance approaches $4\pi\varepsilon_o R$. For many configurations R/H is much smaller than 1 and this approximation is valid. Sphere capacitances are listed below for a number of sizes of possible interest.

Size/Item	Capacitance (pf)
2.54 cm (1 inch) Diameter	1.4
15 cm (6 inch) Diameter	8.5
0.3 m (1 ft) Diameter	17
0.9 m (3 ft) Diameter	100
3 m (10 ft) Diameter	340
truck	2000
large tank	5000

DISCHARGE FLUX RESISTANCE

In any electrostatic hazard configuration, some region or component is being charged and there is a minimum resistance path back to ground level for the charges to drain. In some cases, this discharge path resistance is quite large, and charges will stay fixed for a long period. In other cases, there can be essentially a short circuit back to ground level and charges will drain as fast as they are collected.

The resistances can be estimated based on the characteristics of the path back to ground. For situations in which the electric current will pass through a body of material, the bulk resistivity ρ is pertinent. The resistance of the path is then given by

$$R = \rho \frac{\ell}{A}$$

If the resistance is controlled by surface characteristics, the surface resistivity σ is used.

$$R = \sigma \frac{\ell}{w}$$

where w is the width of the path.

APPENDIX A REFERENCES

A1 Moore, A. D. ed. Electrostatics and Its Applications, John Wiley & Sons, New York, 1973

A2 Soo, S. L., "Charging of Dust Particles by Impact", Journal of Applied Physics, V41, N2, Feb 1970

A3 Eden, H. F., "Potential Hazards of Electrostatic Charging By Powders" (unknown source)

A4 Owen, T. E., "Laboratory Scale Model Studies of Electrostatics in Ship Tanks," Oyes Conference on Electrostatics Hazards in the Storage and Handling of Powders and Liquids, Rosemont, Illinois, 1980.

A5 Hercules Hazards Evaluation & Risk Control Newsletter --"Electrostatics in Materials Handling Operations"

APPENDIX B

SURVEY OF COMPATABILITY DATA

Survey of Compatibility Data

For purposes of the hazards analysis of the WADF facility, the compatibility data represented in Table B-1 were surveyed. Compatibility studies are generally concerned with problems such as slow decompositions leading to poor quality product, and corrosion effects that may take extremely prolonged time periods to develop, in addition to formation of undesireable compounds and inducing runaway reactions. For the purposes of the WADF hazards analysis, the concern is limited to induced runaway reactions and formation of sensitive compounds such as primary explosives.

Results of compatibility studies typically categorize materials being a) compatable (very stable), b) questionable (some reactions observed, but these may or may not be significant) and c) definitely incompatible. By far, the great majority of the results are in the "questionable" category. For the purposes of this survey, only those combinations shown to be definitely incompatible or definitely compatible have been highlighted. These incompatible combinations are the most likely to lead to formation of sensitive compounds or to induce a runaway reaction at elevated temperatures.

The available data represents new and uncontaminated materials, whereas the explosives at WADF are aged and may contain contaminants that are difficult to identify. It must be emphasized that this survey should not be taken as the final work on potential compatibility problems. Rather, it should be viewed only as indicating general types of potential problems that may be encountered. The compatibility survey results are summarized on the following pages. The shorthand notations used in the referenced data sources for many materials are used in the summary.

TABLE B-1 COMPATIBILITY REFERENCES

1. Dangerous Materials Compatibility Study, Wayne R. Wilcox, General Electric Company, February, 1973.

2. Pantex Compatibility Information On the Western Area Demilitarization Facility.

3. Naval Weapons Station, Yorktown, Virginia, Compatibility Information.

4. Bacchus Compatibility Information on the Western Area Demilitarization Facility.

5. Encyclopedia of Explosives, Ordnance Technical Intelligence Agency, Durham, North Carolina.

6. Darcom-R Safety Manual No. 385-100, 17 August, 1981.

7. DTIC Picatinny Arsenal Technical Report, Project No. TM3-5003, Report No. 1, November, 1950.

8. Lawrence Livermore Laboratory, Compatibility Data.

9. Explosives Engineering Design Handbook.

10. Explosivstoffe Nr5/1970.

11. Thermal Decomposition of Explosives, Parts 1, 2, 8.

AMATOL 60-40 TNT/40-60 AN

Incompatible

Copper
Tin

Durez-12041, Wet-Eccesive Reaction
Actex
Actusol
CA8955
CK1350
LL24459
LL24044
Hardware Laquer
CWS Red
DuPont Rhodamine B Extra] Dyes
CWS Green
DuPont Oil Yellow
Most Waxes in General
  Dehydrated Wax 3238
Varnish
  Alox L-1136 & Alox 1263
Shellac
  Olive Drab Paint & Pettman Cement
  In Contact w/ 50/50 Amatol
Protective Coatings (Lacquer & Primers)
  For T-6E1 & T-7 Antitank Mines

More Metals

Cronak Coated Steel Plate
Black Anozinc Unichrome
Zinc Plated Steel @ 65°C & Moisture
Black & Yellow Anozinc
Unichrome Zinc Plated Steel w/Moisture @ 65°C
RED Phosphorous - Decomposition @ 5% level
Vulcanized Fiber Tubing
  (from Dewey & Almax Chem Co.)
All Lacquer Protective Coatings
Gum Rubber "A" B3501
  -Not advisable to use w/any rubber
  Hycar, Neoprene, Butyl, etc.
No Petroleum Hydrocarbon Above 100°C
Steel - Acid Proof Black Paint Coated
      - Copper or Tin Plated

Compatible

Plastic - PVC
Pencolite Adhesive 6-1215 Dry
Durez - 12041 Dry
Zinc Chromate
Sodium Dichromate

Wyandotte Cleaners
No. 147 (Na Silicates & Aluminates)
MK-50 (Saponified Neutral
Petroleum Derivatives) Used in
Cleaning Bomb Surface

Rust Inhibitor, Polar
(Mf'd by Indep. Oil Co. of St. Louis, MO)

Rust Preventatives
Navy Spec 52C18
6d II, Spec. AX5-1759

DuPont Primers
An Chromate, 1063-073, Spec PXS783
Rust Resistant 1063-075 Spec PXS946
Acid Alkali Resistant P373-P-12263
Lacquer Resisting P1063-0-13128
Redoxide - Phenolic P-323-P-13127

Protective Coating
Brevon Coating #2 in APCO Solvent

Decontaminating Agent
Dilute Alkaline Hypochloride Solution
Less than 5% - There Is Better
Material For This Purpose

Dyes
Calco Oil Scarlet II
CW6 Violet

Metals

Iridite Treated Plated Steel Strip @ 65°C

U.S. Rubber Co.'s Rubber Beakers

Less than 1% ZnO in 50/50 Amatol
Is OK Heated to 100°C

AMMONAL (22AN/57TNT/11AL)

Incompatible

Rust Preventative on Fuse
Threads in Shell & Bombs
Spec. AXS-1759

Effect of High Voltage
X-Rays on Stability of
Ammonal - Based on gas evolved by 5gm sample in 40 hours
(120°CX Vacuum Stability Test)

AMMONIUM NITRATE

Incompatible

Copper & Moisture
Hydrides
Phosphide
Carbide
Chlorides
Sulfur
Nitrobodies
Charcoal
Metallic Nitrates
Metal Powders
Petroleum Derivatives
Oxidizable Carbonaceous Materials
Zinc/Galvanized Materials (lowers decomposition temp. to 93.3^{o}C)
Red Phosphorous
UV Light - Decomposes
Al Powder with Greater Than 0.25% Moisture
Fertilizer Grade AN (FGAN)
FGAN (NH_4NO_3) Admixture w/oil, sawdust, asphalt, iron, water at 120^{o}C vac
Picric Acid - Decreases Stability
Zinc Power Admixed, 120^{o} vac explodes above 100^{o}C

AMMONIUM NITRATE Cont'd.

Compatible

Al Powder w/Dry NH_3NO_3

or NH_3NO_3 <0.25% Moisture

Rubber Sheet Stock, Thiokol Sheet, Hycar, Butyl, Neoprene

1% Hydrocarbon Wax @ 120°C

Multiwax D-445	Dallas Wax #71
Wax B	M&M Wax 3238
Socony Vac. Co. PD-893-J	Macrolia
Wax CV-100	Carnauba

Cardboard (Waxed & Unwaxed)
- Nebraska Cardboard
- Nebraska Paper
- Iowa Paper
- Illinois Paper

Dyes

Red-CWS, Calco, DuPont Rhodamine & Extra, CWS Green, Violet, DuPont Oranges, Yellow @ 100°C

Ammonium Picrate @ 120°C

Picric Acid or Tetryl <100°C

Zinc Oxide @ 100°C

BARATOL $(60Ba(NO_3)_2/40TNT)$

Incompatible

Dyes - Oil Blue, Oil Yellow, CWS Yellow, Oil Scarlet 371 (moderate)

Compatible

Methylamino Anthraquinone
NaCl dye

Adhesive - DuPont Adiprene 100 (cured)

BLACK POWDER

"Combustible materials which have absorbed liquors leached from BP constitute a fire hazard & may become explosive" - e.g. lumber must not be released for reuse.

Incompatible

Very Heavy Corrosion - Copper
Bronze
Brass
Nickel
Steel, Copper Plated

Compatible

TNT
Tetryl
Lead Chromate Powder (w/black pdr. Grade A)
Barium Chromate Powder (w/black pdr. Grade A)
Primer Compound PA100
Lead Azide (w/black pdr. Grade A)
Relay Powder Spec. AXS-1277
Non Gaseous Delay Powder

EXPLOSIVE D

Incompatible

Tetryl or Haleite
Lead (Lead Picrate) - note sprinklers w/fusible
Picric Acid
Metals - When Wet (moderate)

@100°C	Nitrocellulose	only recommended for use in pro-
	Nitrocellulose & Nitroglycerine	pellants for exper. purposes (@90°C)

Compatible

Water
Steel
Black Powder
Most Dyes & Coating Materials
Metals - When Dry

HALEITE

Incompatible

Brass & Moisture
Cadmium & Moisture
Copper & Moisture
Nickel & Moisture
Mild Steel & Moisture
Zinc & Moisture

Compatible

Dry Haleite Will Not React with Most Metals

HBX

Incompatible

Moisture Causes Gas Buildup & Casing Rupture (Aluminum - water reaction producing H_2)

HMX

Incompatible (at 120^{o}C)

HMX A-222 w/MMML-1075 (oil)
w/MMMFC-176 (oil)
HMX-312 w/Poly-EM500 (binder)
w/Poly-EM13 (binder)

LEAD AZIDE

Incompatible

Copper & Moisture - reacts to form copper azide (increased sensitivity)
Zinc - corrodes w/moisture rapidly
Alloys of Copper or Zinc
Decomposes Under UV Light (note fire detectors)

Compatible

Water - To Certain Extent That It Doesn't Form Larger Crystals
(For longer storage under water it is dextrinated)
A7970 Cement
"GILSABIND"
Solvent Cement by Cabot
Cleaner by Cabot

No evidence of reaction between dry lead azide and most metals.

NITROCELLULOSE

Incompatible

Solvent Wet w/Chlorosulfonic Acid
Oleum
Active Metals
Powerful Oxidizing Materials
Hydrides
Phosphide
Carbides

Diethylenetriamine-Trinitrate (Excessive Reaction)

PBX-N

PBX9404 Incompatible

Explosive - Nitroquan
Miscel - Glycerol
Miscel - Defoamer Dow Froth 250
Miscel - Urea Regin

Rigid Foam - Down Corn 9-30030
Rigid Foam - X-3-0030
Rigid Foam - Upjohn CPR-302-2

Flex Foam - ABC-31-2
Flex Foam - CPR2030
Flex Foam - CPR-X-2 141A-27
Flex Foam - CPRX-2 141A-34
Flex Foam - ABC-30-1
Flex Foam - ABC-31-1

Adhesive - Dow Corn A-4000
Adhesive - Furane
Adhesive - Aerobond H7-Part-A
Adhesive - Aerobond H7-Part-A
Adhesive - Epoxy 633111
Adhesive - Atlas Minepoxy Bond
Adhesive - Thixon XAB-772
Adhesive - Dow Corn RTV-732 (uncured)
Adhesive - Loctite 307
Adhesive - Loctite 308
Adhesive - Loctite 310
Adhesive - Loctite 311
Adhesive - BiPax Tra-Duct
Adhesive - 422-95
Pot Comp - Dow Corn RTV 502
Pot Comp - Dow Corn S-140
Pot Compt - Mansville Duxseal

Crack Detector - Pruss Blue
Crack Detector - Food Color

Oil - Gen Elec Verslube 6-300
Oil - Wesson Salad

Metal Load - Blackbird 3126
Metal Load - Blackbird 3145-1
Metal Load - Bendix Blackbird #1
Metal Load - Bendix Blackbird #2
Metal Load - Bendix Blackbird #2-A
Metal Load - Blackbird 2-3147
Metal Load - Blackbird 1-3151
Metal Load - 102-1236A
Metal Load - Blackbird 102-1236A
Metal Load - Gen. Tire Ethane
Metal - Cobalt

PBX9407 (No Carbon)

Explosive - PETN Lot B-1084

PBX9407 (Burlington)

Adhesive DuPont Adiprene Blue
Adhesive DuPont Adiprene Green

PBX9407 (A-142)

Adhesive - MMM #465
Eastman 910
DuPont Adiprene

PBX9007 (A-014)

Adhesive - Bakelite Resin
Palmer Cement 752 Batch 926
MMM 4-9146
Rigid Foam - Nopco Foam H-102

PBX9010 (A-099)

Metal Load - Gen. Tire Genthane
(K-099) Adhesive - Atlas Min-Epoxy Bond

PBX9404

Compatible

Metal - Platinum

Adhesive - DuPont Adiprene

Crack Detector - F.D.-C Color #2 Red
Crack Detector - F.D.-C Color #3 Green
Crack Detector - Magna Flux Zyglo ZE-3
Crack Detector - Magna Flux Zyglo ZE-6
Crack Detector - Magna Flux Zyglo ZL-1C
Crack Detector - Magna Flux Zyglo ZL-4B
Crack Detector - Magna Flux Zyglo ZL-17A
Crack Detector - Magna Flux Zyglo ZL-18A
Crack Detector - Magna Flux Zyglo ZL-22
Crack Detector - Magna Flux Zyglo ZL-30A

Rigid Foam - Polyurethane Sta Foam
Rigid Foam - Bendix K1013-1049
Rigid Foam - Bendix p683-718
Rigid Foam - Bendix Part 1436038
Rigid Foam - Bendix Part 194573
Rigid Foam - Bendix Part 99232
Rigid Foam - Upjohn Cpr - 301-3C

Rubber - Dow Corn 5-5420

Misc - Emralon
Silicate

Oil - Lub. Oil
Dow Corn Comp-4

Pot Comp - Dow Corn RTV521
Dow Corn Q90092
Dow Corn X9-0112
Dow Corn 092009/29
Gen Elec RTV-60-3243
Dow Corn S-140 Lot 230223
Dow Corn RTV-630

Struct. Pla. - Gen Elec Lustran I-710
Phenoxy 8060
Gen Elec Lexan 134
Mobay Merlon M-50
Gen Elec Lexan 104
Mobay Merlon 60

Metal Load - KW 1920 SPL3242-A
KW 1920 SPL3242-D
Rattan B

Metal - Platinum
Lead
Silver
B-and-A Nickel Code-2011
LRL Alloy D-38 Batch 8272

Adhesive - DuPont Adiprene L-100 & L-167
Dow Corn A-4000
Laminac 4116
Dow Corn S-140
S-731
S-891
MMM Tape - 60
MMM Mylar - 56
Laminac

Binder - Hypalon 310140-1
Union Carbide 4-3602

PBX9007

Compatible

Adhesive - DuPont Adiprene Yellow

Struc. Pla. - Phenoxy 8060
Gen Elec Lexan 134
Mobay Merlon M-50
MMM #465

PBX9407

Compatible

Struc. Pla - Phenoxy 860
Gen Elec Lexan 134
Mobay Merlon M-50

Adhesive - MMM #466
MMM #Y-9146
Sprayon Stick Quick
DuPont Adiprene L-100

PENTOLITE

Incompatible

May Have Tendency to Separate Into Its Ingredients...PETN & TNT Under High Temperatures.

Compatible

Has No Reaction with Most Metals
(Highly Compatible When Dry)

PETN

Incompatible

Adhesive - (SHJELDAHL G-100 & G-107)
(MMM SCOTCH 465)
(MMM &-9146)
(H-Film)
(MMM Y-3736)
(POLYKEN XO-1-3)
(POLYKEN XO-1-2)
(POLYKEN XO-1-5)
(POLYKEN TO-1-1)
(MMM Tape 466)
(MMM Tape 465)
(Phenolic Adhesive on Regal Mylar A-1)
(DuPont Adiprene L-100)
(PER-331)
(P01B-101)
(HA1-B-101)
(Bet. Finish Liquid Envel. 33-20)
(Bet. Finish Liquid Envel. 33-3267)
(DuPont Adiprene - yellow, amber, blue, green)
(Bakelite Resin)
(NA1B)
(Lexham)
(Cerambound 503-cured & uncured)

Flex Foam (CPR-2054)
(LRL Comp 14)
(XB-42-8A)
(CPRX2-141A)
(LRL Comp 22)
(MMM Scotch 221)

Plastic (Mesa Epiall) 1914
(Mesa Epiall) 1906
(DEHP)

Rigid Foam (Dow Corn. Q30030)

Miscellaneous - (Foote-Chem Eucryptite)
(Foote-Chem Zerifal)
(Polyethylene Black Bag)

*Explosive - (PBX9407)
(PBX9407 no carbon)

Structural - DAP-(Blue)

Pot Comp. (Manville Duxseal)

Metal - Nickel

Compatible

Structural - DAP-(Green)
Polysulfone

Structural Pla: P-1700 C-30-C

Crac Detec: Pigment

Dry PETN & Metals

PICRATOL (Explo. D/TNT) (52/48)

Incompatible

Lead -(Due to Explo. D)
Silastic (Dow Corning #732 uncured)

Observe All Precautions Made Necessary By The Characteristics of TNT & Ammonium Picrate

RDX

Incompatible

Asphalt Compounds

Compatible

Aluminum
Stainless Steel

NITROGUANIDINE

Incompatible

Wet w/Acids
Water Unsat. Aldehyde
Anhydride
Lactone
Acrylic
Active Metals
Hydrides
Acyl Halide
Carbide Allyls
Chlorohydrin

Unsat. Ketones, Powerful Oxidizers, Phosphide, Polymerization Catalyst, Carbide, Allyl Cpds., Vinyl Acetate, Sensitive to Water.

Compatible

RDX J-12

COMP B

Incompatible

Hard Unique Liner
Soft Unique Liner
Essex Liner
TNT & Asphalt Compounds
(mainly decomposition & quality control)

RED PHOSPHORUS

Incompatible

Oxidizing Agents (Forms Very Sensitive Mixtures)

TETRYL

Incompatible

American Seal 'Locktite'

TETRYTOL (Tetryl/TNT)

Incompatible (Minor i.e. corrosion incomp.)

Dry	Slightly Corrodes Magnesium & Al Alloys
Wet	Copper
	Brass
	Aluminum
	Magnesium - Aluminum Alloys
	Mild Steel
	Mild Steel Plated w/Cadmium

TNT

Incompatible

Chlorosulfonic Acid
Acid, Oleum
Active Metal
Oxidizing Material, Powerful
Acetone or Acetonitrite Solutions w/Amines
(forms hypergallic reactions)
Cavity Liners at High Temperatures
Alkalies and Ammonias
Hard Unique Liner
Tuffseal Liner
TSl Liner
Plastonium Liner
Asphalt Compounds (decomposition)
Cardboard Fibers, KNO_3, Activated Carbon (lowers temp. for runaway)

Compatible

MISCH-MET #4

TRITONAL (TNT/ALUM) (80/20)

Incompatible

Alkalies and Ammonias

Moisture (Aluminum - Water Reaction Produces H_2 Gas & Could Result in Pressure Rupture)

WHITE PHOSPHORUS

Incompatible

Oxygen (air)
Polymerization Catalyst
Oxidizing Materials - Mild & Powerful
Alkali
Active Metal

DBX (aluminized)

Incompatible

Copper and Brass ("like Amatol")

Reacts with Metals in Same Manner as Amatol

DOUBLE BASE PROPELLANT (HEN-12)

Incompatible

643 Entries in Bacchus Compatibility File

Note, HEN-12 is an extremely sensitive and reactive double-base solventless propellant, which is used as a worst-case by Hercules. In general, if a sample substance is compatible with HEN-12, it is compatible with any conventional NC base propellant.

APPENDIX C

RUNAWAY REACTION IN LIQUID EXPLOSIVE HOLDING VESSELS

Runaway Reaction in Liquid Explosive Holding Vessels

Physical Aspects

By far the most dominant scenarios shown to be hazardous from the fault tree analysis of the Washout/Steamout Building North Tower and the Refining Building involved runaway reactions in holding vessels, such as the melt kettles and the separator vessel in the North Tower. In each case, several incidents per year were computed. Since this is largely an indication of the scarcity of information available on which to make a truly objective analysis, it is suggested that testing be conducted in order to more realistically assess this problem. In this section, the method of analysis used for evaluating runaway reaction is presented along with the available data and conclusions based on the analyses.

The Batelle Report, Volume IV (reference C1), contains several excellent "runaway reaction" articles describing the experimental and analytical methods, the state of the knowledge, and what it all means relevant to WADF. These articles include the following:

1) Peterson, R., L. R. Rothstein, and J. H. Smith, "Thermochemistry and the Demilitarization of Explosives", NWSY TR 76-2, July 1976.
2) Letter to Dr. L. Rothstein from T. B. Joyner, dated 17 December 1975.

In addition, a 1970 article by Groothuizer, Lindeijer, and Pasman in Explosivestoffe 5 (1970) 97 was referenced by Peterson et al and proved to be quite informative.

The classical theory of thermal explosion is summarized in the Peterson paper and will not be repeated here. Two relations characterize the runaway reaction phenomena. The critical temperature, T_c, (below which conductive heat transfer is adequate to remove heat produced inside the body of explosive by exothermic reaction) is given by

$$T_c = \frac{E}{R \ln \dfrac{\rho a^2 Q Z E}{\lambda R T_c^2 \delta}} \qquad \text{(C1)}$$

where T_c = boundary temperature at critical condition (^{o}k)

ρ = density (g/cc)

λ = thermal conductivity (cal/cm^{o}k sec)

Q = heat of reaction per unit mass (cal/g)

Z = pre-exponential factor (sec^{-1})

E = activation energy (cal/mole)

R = gas constant (1.987 cal/mole^{o}k)

a = significant dimension (cm)

- slab half thickness
- radius of cylinder
- radius of sphere

δ = shape factor

- 0.88 for slabs
- 2.00 for cylinders
- 3.32 for spheres

The time to explosion, t_e, is given by

$$t_e = \frac{CRT_o^2}{QZE} \exp\left(\frac{E}{RT_o}\right)$$

where

C = specific heat (cal/g^{o}k)

T_o = boundary temperature (^{o}k)

It must be remembered that equation C1 is derived based on conduction being the dominant mode of heat transfer. Therefore, results correspond more closely to the non-agitated condition in liquid explosive holding vessels. Equation C2 assumes no heat transfer - i.e. views a region deep within the bulk of material where temperature gradients are gradual. In these respects, the thermal explosion model will be conservative.

Mixing also serves to blend in local high temperature regions that might develop if a contaminant enters the vessel. In this case, mixing is critical to prevent runaway reaction. The thermal explosion model does not account for localized reactions from such a contaminant. It assumes everything is homogeneous, and, therefore, may not be conservative with regard to local reactions.

In spite of the model's simple view of the melt kettle as containing a homogeneous pure chemical mixture in a simple configuration such as a cylinder, the model will be used to help map out conditions where problems may be present. The model provides the critical temperature and time to explosion for a pure chemical mixture as long as the parameters Q, Z and E are known for that mixture. These parameters have been derived for pure explosives and are presented in the paper by Peterson, et al for several materials. As was emphasized in that paper as well as in many others, the values for pure explosives are not relevant for aged or contaminated explosive materials. You essentially have a new chemical, and if the contaminant or decomposition products are uniformly mixed into the explosive a new set of parameter values (Q, Z and E) should realistically describe the susceptibility of the new mixture to runaway reaction. Naturally, if the mixture is not uniform, local effects may dominate. However, in order to help map out the potential runaway reaction hazards, the assumption was made that the thermal explosion model can be used for aged or contaminated materials; you just need to determine the pertinent values of Q, Z and E. In essence, these are used as scaling parameters.

The thermal explosion model was used to compute the critical temperature and time to explosion versus temperature for selected cases extracted from the literature (see Figure C1). TNT based materials were considered because at the relatively low temperatures to be experienced in the holding vessels, even under the worst conditions (126°C), TNT will be the liquid phase and should dominate. The liquid in the vessel can be viewed as TNT "contaminated" by other materials present.* Curves 4 and 5 at the far right of Figure C1 show time to explosion t_e versus temperature for pure TNT. These curves were based on activation energies and pre-exponential factors presented in references C2 and C3.

For pure TNT, the times to explosion are fairly long (at least 10 hours at 130°C) in even the worst case shown. The explosives to be melted out of items at WADF will not be pure explosive. They will be aged and are likely to be contaminated. Therefore, the pure TNT curve represents an ideal that will not be realized. Joyner in reference C3 presented values of apparent activation energy and pre-exponential factor for a TNT-asphalt mixture. The

*This may not always be true. Indications are that the more reactive phase (e.g. RDX in TNT) can dominate. Therefore, curves based on TNT alone may not be reliable.

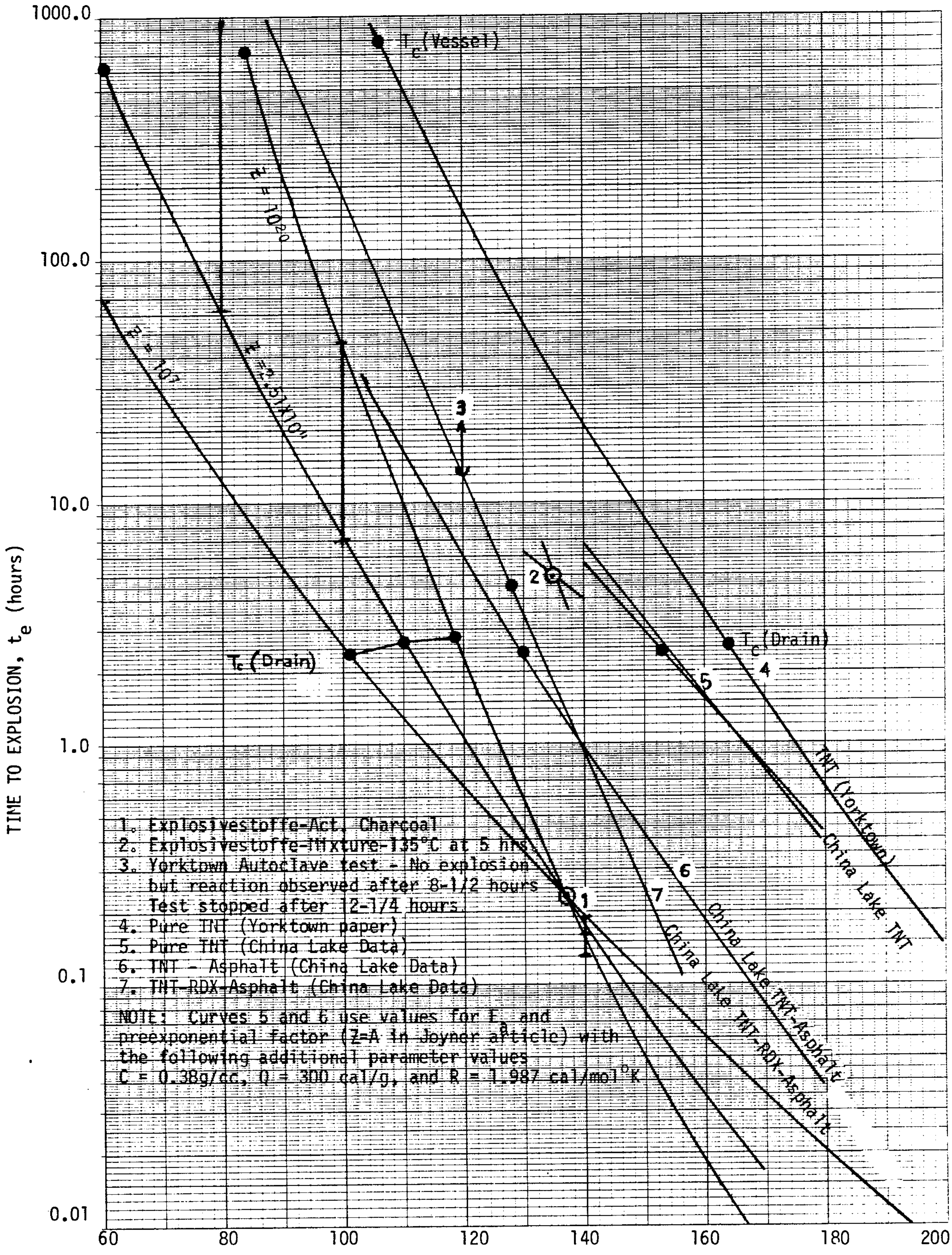


FIGURE C1 Time to Explosion Map

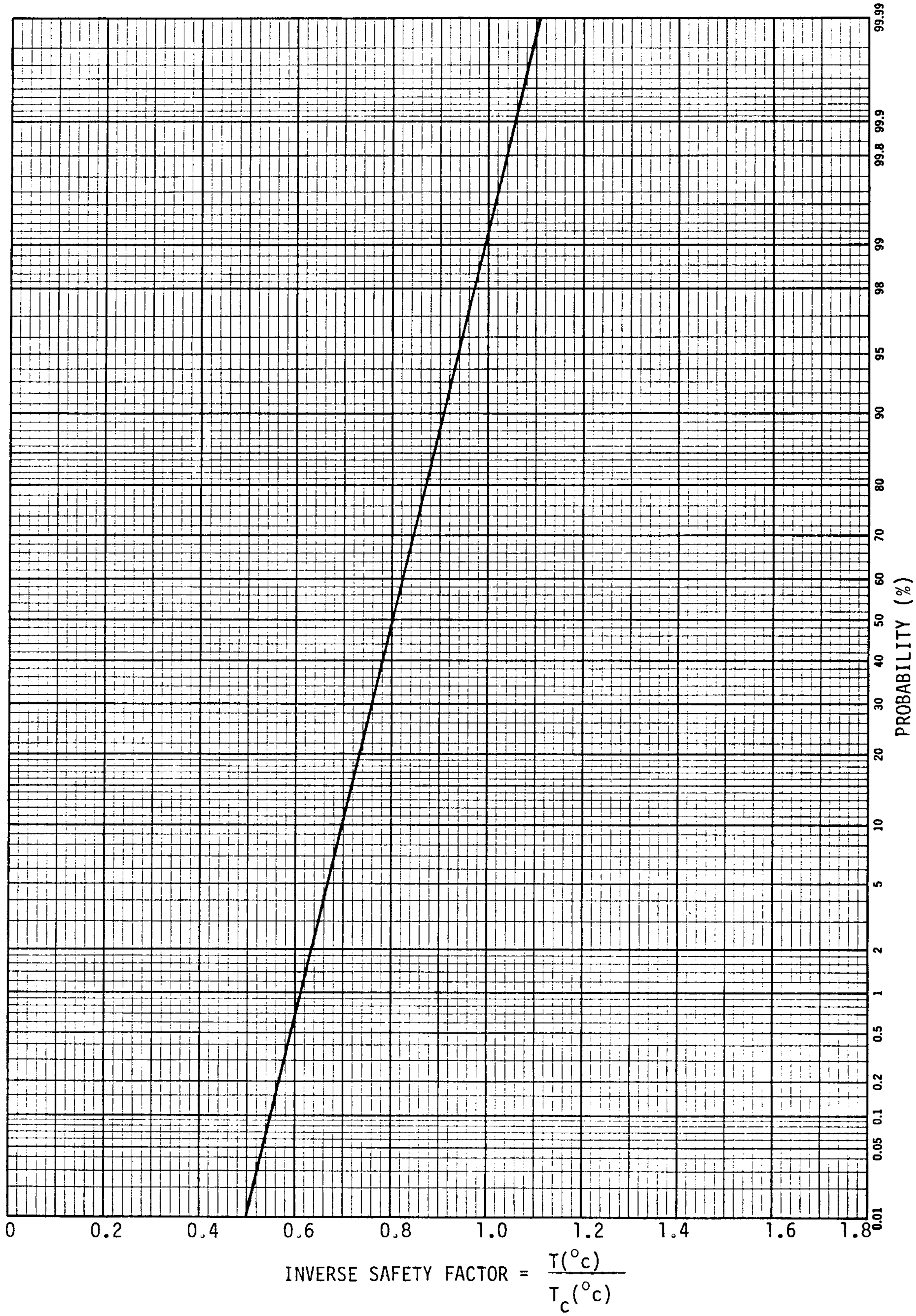


FIGURE C2 Subjective Distribution To Account For Uncertainty In T Value corresponding t_e-T relation is labeled in Figure C1 as curve 6. This curve has been adopted in the present analysis as representing a typical explosive to be handled at WADF. It should be noted that many items to be steamed out or melted out at WADF have asphalt liners.

The fan shaped region at point 1 of Figure C1 is an attempt to define a "worst case contaminant" envelope. The point labeled 1 is a single data point obtained from tests conducted in Holland (reference C4) to investigate an explosion in the KNSF melt shop (Muiden, Holland) June, 1966. In that test TNT was contaminated with activated charcoal and an explosion occurred at 135°C in 15 minutes. The shaded (fan shaped) region was obtained by assuming a wide range of pre-exponential factors Z (from 10^7 sec^{-1} to 10^{20} sec^{-1}) and solving for the activation energy required to produce an explosion in 15 minutes at 135°C. The centered curve corresponds to the value of Z used for pure TNT in the Yorktown paper (reference C2). This curve has been chosen to represent a worst case contaminant in our analysis. The shaded region should conservatively represent the uncertainty in the relation for the Dutch activated charcoal-TNT test. It should be noted that in the reference C4 (Dutch Experiments), cardboard and glass wool also significantly decreased the time to explosion. It was hypothesized that such materials inhibit heat transfer locally allowing hot spots to form. Point 2 in Figure 1 is another data point from the Dutch test series, in which a mixture of TNT with 0.5 percent propellant, 0.5 percent soap, 0.5 percent cardboard, 0.5 percent iron, 2 percent ammonium nitrate and a trace of KC7 exploded at 135°C in 5 hours.

Point 3 on Figure C1 corresponds to a test conducted at NAVWPNSTA Yorktown (reference C2) in which a MK25 Mod 1 HBX-1 loaded mine was exposed to 15 psig steam in an autoclave for several hours. No explosion occurred, but bubbling/gassing was observed at $8^1/_2$ hours and resulted in shutdown by $12^1/_2$ hours. Similar bubbling has been noted to be a precursor to explosion in other tests or incidents.

Other data is available to be plotted on a map such as Figure C1, but the data shown indicates that pure TNT represents an overly optimistic limit, curve 6 (TNT-asphalt) is not unreasonable to characterize a typical, hopefully conservative, mixture for WADF, and the middle curve associated with data point 1 (TNT-activated charcoal) is probably a reasonable "worst case" for contaminated explosive. To better evaluate this problem, it is strongly suggested that more comprehensive testing be conducted to determine the effect of other "real world" contaminants on all the explosives to be processed at Hawthorne. Such testing should be of the type conducted by Joyner (reference 2, parts 1-7) to evaluate the pertinent reaction rate constants, and/or of the type conducted by the Dutch to evaluate the melt shop incident (reference 3).

Probablistic Aspects

To estimate the probability of a runaway reaction occurring, the following factors were considered:

1) the probability that the mixture temperature exceeds the critical temperature for runaway reaction, $P(T_\delta \geq T_c)$
2) the probability that the hold time exceeds the time to explosion at the exposure temperature, $P(t \geq t_e)$*

The overall probability that a runaway reaction occurs in the vessel is taken to be the product of these two values.

Consider first the probability that the critical temperature will be exceeded ($T_\delta \geq T_c$). Two operating temperatures are of concern in the WADF system. These are the normal operating temperature of up to 119°C (15 psig steam), and the maximum credible temperature limited by the rupture disk pressure rating, 126°C (22 psig). Six configurations are of interest:

Pure TNT (overly optimistic)
- in vessel
- in drain line

Normal (aged) material at WADF
- in vessel
- in drain line

Severely Contaminated Explosive
- in vessel
- in drain line

From Figure C1, curves 4, 6, and 1 are used to represent the ideal pure explosive, a typical WADF material, and a severely contaminated explosive, respectively. Because there is considerable uncertainty that these curves are realistic for WADF, a subjective probability distribution has been developed

*t is the hold time

(Figure C2). This curve is subjective and is used to avoid making "Go-No-Go" type decisions which would be inappropriate in this case. Based on Figure C1 and C2, the probability of $T \geq T_c$ can be derived for each case considered.

Case	$P(119°C \geq T_c)$	$P(126°C \geq T_c)$
Pure TNT (overly optimistic) in vessel (T_c=106°C)	0.9999	1.0
in drain line (T_c=164°C)	0.17	0.34
Normal Material at WADF in vessel (T_c=77°C)	1.0	1.0
in drain line (T_c=130°C)	0.89	0.973
Severely Contaminated Explosive in vessel (T_c=60°C)	1.0	1.0
in drain line (T_c=100°C)	0.9995	1.0

As can be seen, the subjectivity of FigureC2 really makes little difference. For all practical purposes, the critical temperature will be exceeded in all cases of interest. Even 0.17 is a relatively high probability.

For the operating temperatures being considered, the time to explosion can be read off of Figure C1.

	Pure TNT	Typical WADF Material	Severe Contaminant
119°C (normal)	t_e = 190 hr.(8 days)	t_e = 6.7 hr.	t_e = 1.2 hr.
126°C (maximum)	t_e = 90 hr. (4 days)	t_e = 3.5 hr.	t_e = 36 min. (0.6 hr.)

The probability that the hold time exceeds the time to explosion, $P(t \geq t_e)$, was derived for each case by considering the operating schedule.

For the separator in the North Tower, it was assumed that normal operation involves 2 hour holds with a standard deviation of ½ hour. This is based on all 8 tilt tables being used to fill the separator to the 180 gallon level prior to beginning to fill melt kettles. Figure C3 shows the cumulative probability distribution for this case.

For abnormally long holds in the separator (i.e. due to equipment problems downstream), it was assumed that a typical prolonged hold involved an additional 2 hours (total hold of 4 hours) and that it is quite unlikely that a hold will occur beyond one shift (say a probability of 0.05 that this will occur). The resultant probability distribution is shown in Figure C4.

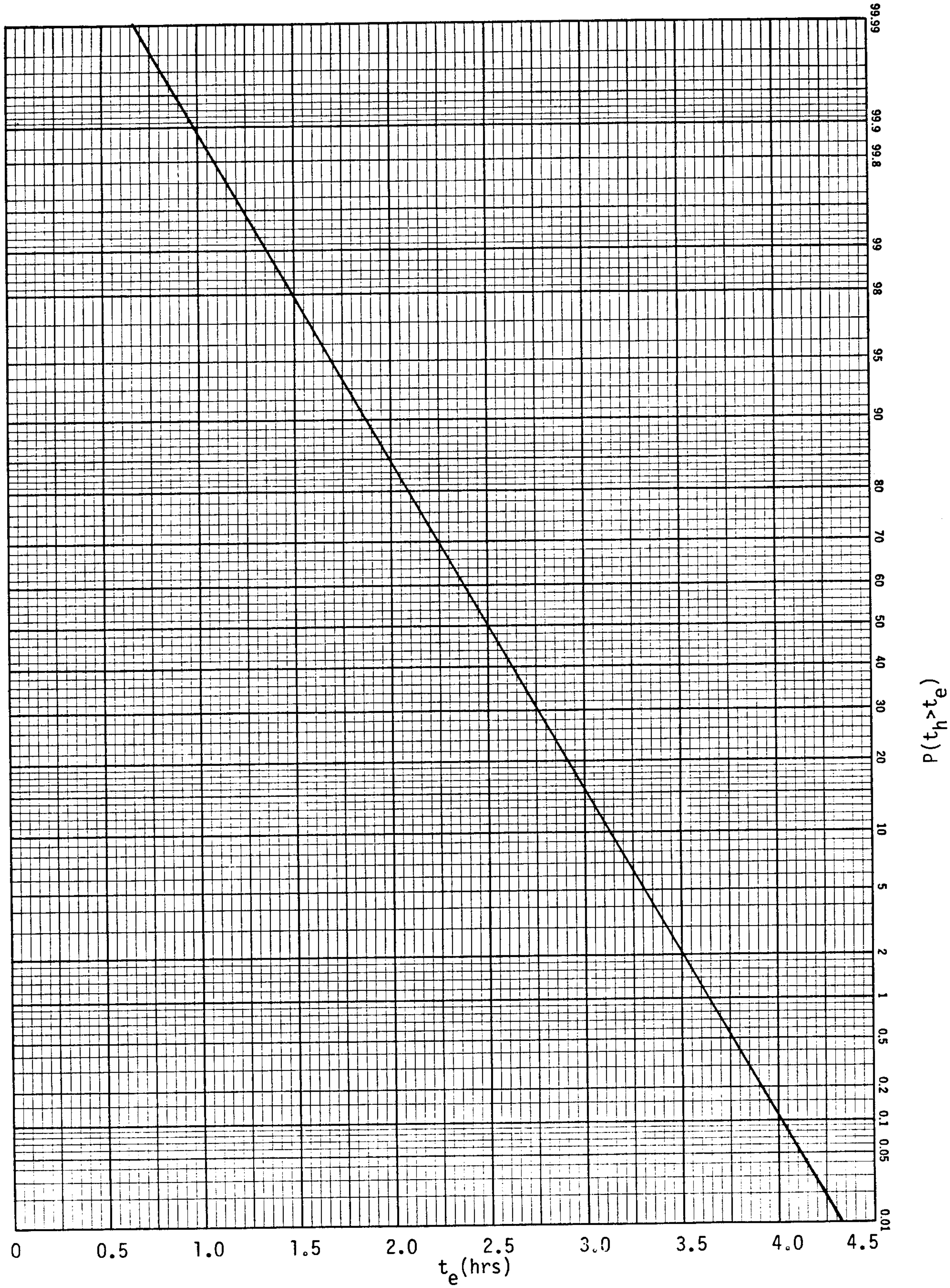


FIGURE C3 Probability of Hold Time Being Greater Than Time to Explosion (Separator - Normal Hold Times)

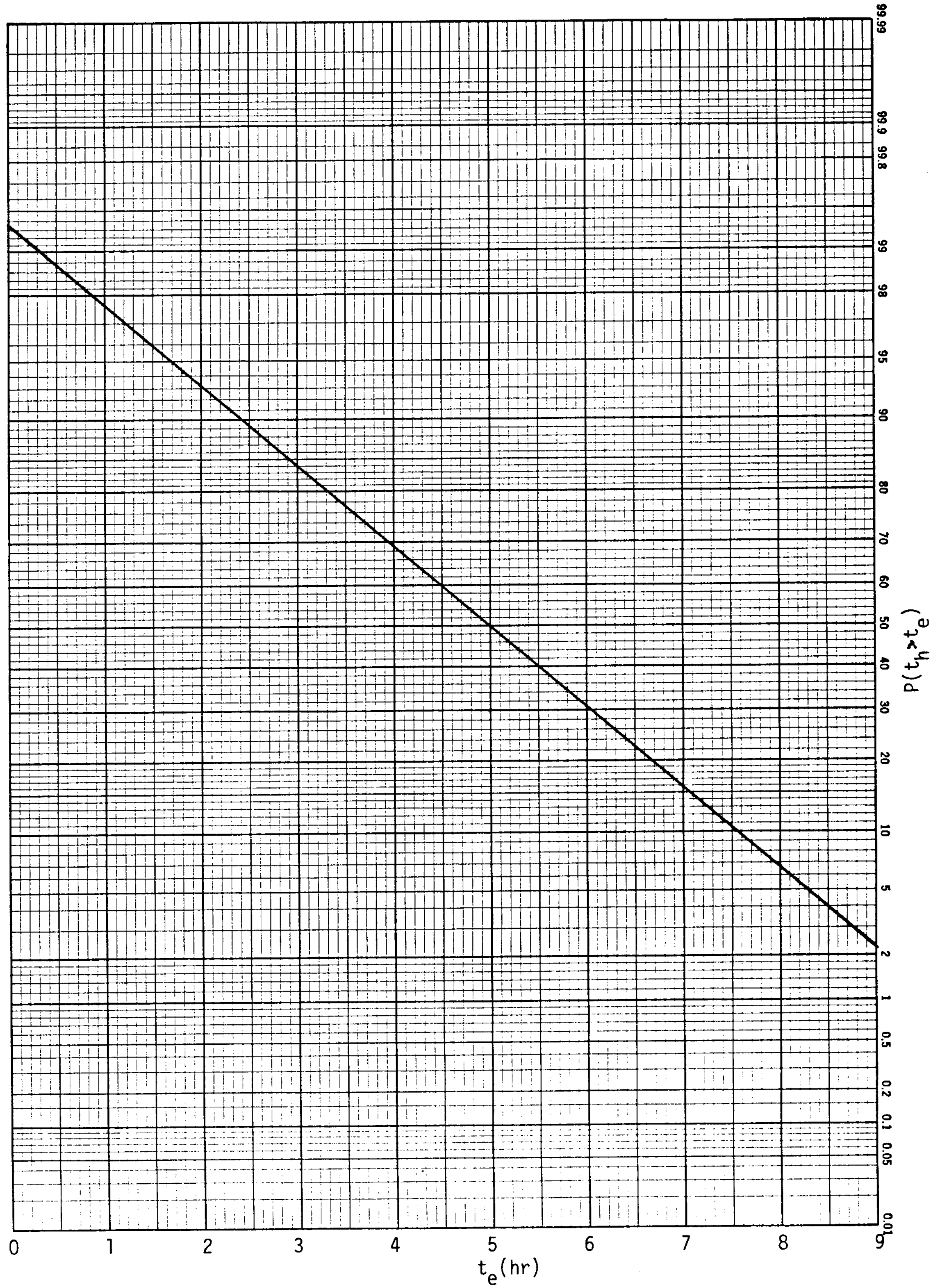


FIGURE C4 Probability of Hold Time Being Greater Than The Time To Explosion (Separator - Abnormal Holds)

Similar rationales were used to develop Figures C5 and C6 for the melt kettles. From Figures C3 through C6, the probability of the hold time exceeding the time to explosion can be derived. The probabilities of runaway reactions occurring are summarized in Table C1. From Table C1 it is seen that pure TNT would never be expected to be involved in a runaway reaction; severely contaminated explosive would always be expected to runaway; and the materials "expected for WADF" fall in between. For these cases, normal operating times and temperatures have low probabilities of runaway. Abnormally long holds in some cases drive the probability up toward unity, particularly when combined with excessive operating temperatures.

It must be remembered that this analysis is considered to be conservative. The effects of agitation were not considered. Agitation should enhance heat transfer and reduce the chance for local heat buildup, particularly due to contamination. The probabilities shown in Table 1 were used in the fault tree analysis, and consequently runaway reaction was determined to be the major problem from that analysis. IITRI personnel feel that such a conservative analysis must be used because of the inadequate information that currently exists concerning the susceptibility to runaway reaction of chemical mixtures that are aged and likely to be contaminated such as will exist at WADF. Therefore, further testing to better understand this hazard is quite important.

If a runaway reaction does occur in a holding vessel at WADF, the existing protective measure may prove to be inadequate. A "top surface" relatively gentle deluge probably will cause a crust to form and protect the reaction beneath the crust from further cooling effects. Apparently, a more forceful deluge is undesireable because of resultant gas generation. The equipment in place cannot be modified easily to accomodate a fast dump to pans, although a slow dump may help in some cases. At the present time there do not appear to be any simple solutions.

Of special concern are the long drain lines at the bottom of these vessels. These pipes will contain stagnant explosive, unaided by agitation in the vessels. Therefore, in these cases, the initiation probabilities estimated above may not be overly conservative. The initiation probability for material expected to be handled at WADF was calculated to be 0.11 in the melt kettle drain at

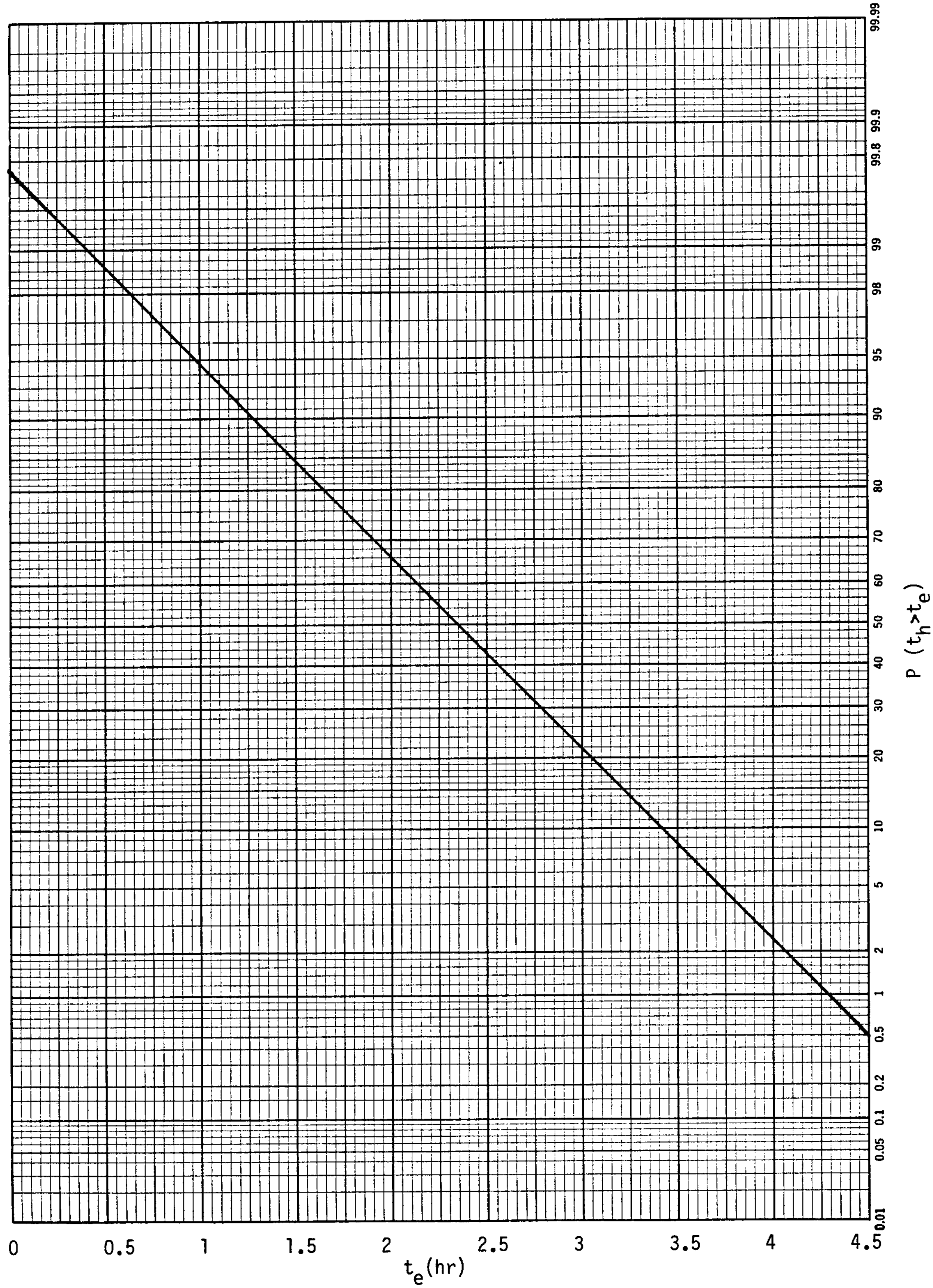


FIGURE C5 Probability of Hold Time Being Greater Than Time To Explosion (Melt Kettle Normal Hold)

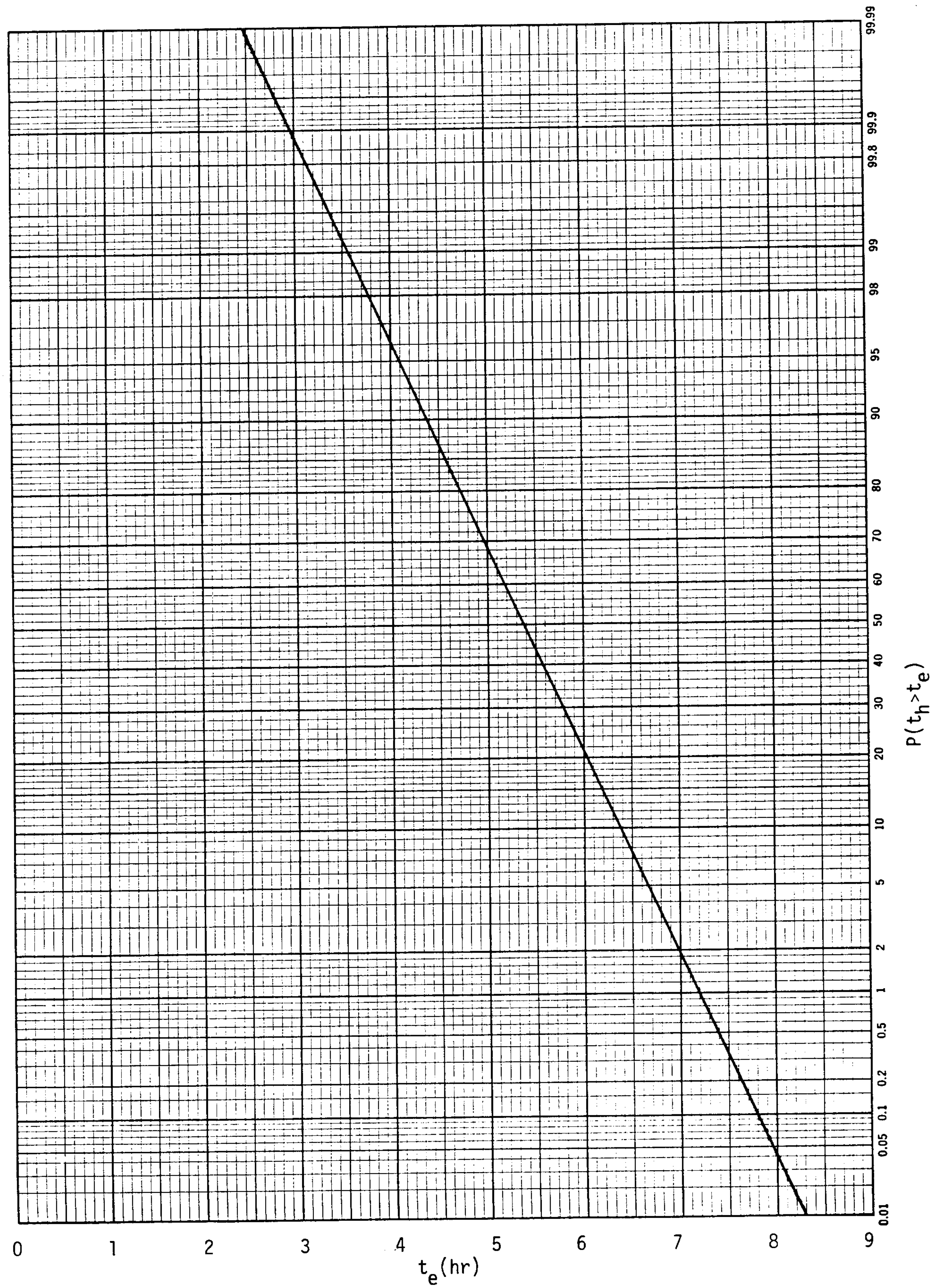


FIGURE C6 Probability of Hold Time Being Greater Than Time To Explosion (Melt Kettle - Abnormal Hold) normal operating temperature with a long hold. It was estimated to be 0.74 with high temperature steam in combination with a long hold. This section of pipe is not steam jacketed so the wall temperatures will be somewhat lower than those conservatively assumed in this analysis. However, this conservatism is considered to be justified. Therefore, it is suggested that the valves be moved as close to the vessel exit as possible to minimize the stagnant space present in the drains.

In summary, a number of problems prohibit accurate and reliable quantification of the potential for runaway reaction in liquid explosive holding vessels. These include the following:

- theoretical models assume homogeneous chemical mixtures, whereas local effects may dominate in actual runaway reactions, particularly those induced by contaminants
- theoretical models do not consider convection heat transfer, whereas some degree of agitation will be present in the holding vessels
- available experimental data is primarily for pure explosives, whereas the materials to be processed at WADF are likely to be aged and contaminated.

Available data with contaminated explosives or materials exposed to melt-remelt cycles indicates that the susceptibility to thermal explosion can be increased significantly.

Data of this type is insufficient to reliably quantify the hazard. Although similar operations have been conducted in the past, some incidents of a similar nature to that evaluated here have been reported (e.g. see Appendix E -- melt-pour operations, DDESB File numbers 433, 235, 518, and 989). Thus, IITRI personnel feel that sufficient unknowns exist to demand a conservative approach with regard to safety. It is strongly recommended that further simulation testing such as that done in Holland (reference C4) and/or at China Lake (e.g. reference C3) be conducted to better characterize the potential for runaway of materials likely to be processed at WADF. Such testing should be accomplished before WADF goes operational.

TABLE C1 PROBABILITY ESTIMATES FOR RUNAWAY REACTION

Material Type/Configuration	Temperature Exposure	$P(T \geq T_c)$	Hold* Case	$P(t \geq t_e)$	Overall Runaway Probability
Pure TNT					
in Vessel	119°C	0.9999	SN	$<10^{-14}$	∿0
			SA	"	0
			MN	"	0
			MA	"	0
	126°C	1.0	SN	$<10^{-14}$	∿0
			SA	"	0
			MN	"	0
			MA	"	0
in Drain	119°C	0.17	SN	$<10^{-14}$	∿0
			SA	"	0
			MN	"	0
			MA	"	0
	126°C	0.34	SN	$<10^{-14}$	∿0
			SA	"	0
			MN	"	0
			MA	"	0
Expected WADF Material					
in Vessel	119°C	1.0	SN	$<10^{-14}$	0
			SA	0.09	0.09
			MN	∿ 0	0
			MA	0.12	0.12
	126°C	1.0	SN	1.3×10^{-3}	1.3×10^{-3}
			SA	0.6	0.6
			MN	0.02	0.02
			MA	0.76	0.76
in Drain	119°C	0.89	SN	$<10^{-}$	0
			SA	0.09	0.053
			MN	∿ 0	0
			MA	0.12	0.11
	126°C	0.973	SN	1.3×10^{-3}	1.27×10^{-3}
			SA	0.6	0.058
			MN	0.2	.019
			MA	0.76	0.74
Severely Contaminated Material					
in Vessel	119°C	1.0	SN	0.95	0.95
			SA	0.92	0.92
			MN	1.0	1.0
			MA	1.0	1.0
	126°C	1.0	SN	0.998	0.998
			SA	0.96	0.96
			MN	1.0	1.0
			MA	1.0	1.0

Material Type/Configuration	Temperature Exposure	$P(T \geq T_c)$	Hold* Case	$P(t \geq t_e)$	Overall Runaway Probability
in Drain	119°C	0.9995	SN	0.95	0.95
			SA	0.92	0.92
			MN	1.0	1.0
			MA	1.0	1.0
	126°C	1.0	SN	0.998	0.998
			SA	0.96	0.96
			MN	1.0	1.0
			MA	1.0	1.0

* Key - SN - Separator vessel with normal operation

SA - Separator vessel with abnormal long holds

MN - Melt kettle with normal operation

MA - Melt kettle with abnormal long holds

APPENDIX C REFERENCES

C1 Zeidman, G.G., B.C. Kim, A.E. Weller, and W.A. Smith, "A Study of Equipment Processes, and Systems for a Demilitarization Facility at NAD, Hawthorne, Nevada," Phase II, Establishment of Design Criteria, Volume IV for Western Division Naval Facilities Engineering Command by Battelle Columbus Laboratories

C2 Petersen, R., L.R. Rothstein, and J.H. Smith, "Thermo Chemistry and the Demilitarization of Explosives", Naval Weapons Station, Yorktown, Report NWSY TR 76-2, July 1976.

C3 Joyner, T.B., "Thermal Decomposition of Explosives, Part 2, Effect of Asphalt on the Decomposition of TNT", Naval Weapons Center Report TP4709, April, 1969.

C4 Groothuizen, E.W., Lindeijer, and H.J. Pasman, "Investigation into the Cause of the Explosion in the TNT Melting Shop of the KNSF at Muiden", Explosivstoffe Nv.5/1970.

APPENDIX D

Discussions of Selected Scenarios and Probability Estimates

In this appendix, typical scenarios are described in order to demonstrate the rationale used to estimate probability of occurrence. These example cases were chosen from the analysis of the North Tower of the Washout/Steamout Building. The scenarios are presented in decreasing order of estimated probability of occurrence. It should be noted that the most dominant North Tower problem areas involved runaway reactions, which are not discussed here. Appendix C is devoted to that specific subject area. Not all of the North Tower scenarios are presented here.

Lance Impact Initiation from Rough Handling During Steamout.

ESTIMATED FREQUENCY = 5 x 10^{-3} year

Discussion

In this scenario the operator who advances the steam lances is extremely emotional. As a result, he slams the lance forward with great force, impacting it onto internal piping within the item. It is judged that an operator will have such an emotional problem once per year and that one of these occasions in ten trials will lead to him slamming the lance into the item (probability for human error under stress).

The major question in evaluating this hazard is how much energy can the operator impart in shoving the lance? To estimate this stimulus energy level, several human engineering references were consulted:

1. Woodson, W.E., Human Factors Design Handbook, McGraw-Hill Book Company, New York 1981.
2. Van Cott, H.P. and R.G. Kinkade (editors), Human Engineering Guide to Equipment Design, American Institutes for Research, Washington DC 1972.
3. Greenburg, L. and D.B. Chaffin, Workers and Their Tools, A Guide to the Ergonomic Design of Hand Tools and Small Presses, Pendell Publishing Company, Midland, Michigan 1977.

These sources provided human force levels, either the maximum achieveable or the level acceptable for design. Some typical force levels extracted from these sources are summarized below:

Forearm Lift (Upward); 267 nt (60 lb)	(maximum force expectation)
Lever Push (Foreward); 579 nt (130 lb)	(maximum force expectation)
Sitting, Hand Control Push; 410-615 nt (92-138 lb)	(50th percentile -- depends on upper arm angle)
Lifting and Carrying a Package; 223-423 nt (50-95 lb)	(50th percentile -- depends on lift height above the floor)
Static Push; 628-864 nt (141-194 lb)	(mean values)
Push Foreward; up to 223 nt (50 lb)	(design criteria)
Upward with Arm; up to 107 nt (24 lb)	(design criteria)

Based on this, it is not unreasonable to expect that an operator could apply 445 nt (100 lb) of force to shove the lance into an item under unusual circumstances. If this force level is maintained for a 0.3 m (1 ft) push, about

120 joules would be applied to the impact. If the force level decreases linearly to zero over the push, about 60 joules would be imparted during the impact.

A number of other calculations were made considering commonplace human activities, e.g. how far can a baseball be thrown. These calculations yielded energy levels more typically on the order of 10 joules. If 10 joules of energy is applied to a 0.1 cm^2 area during a lance impact, the stimulus would be 10^6 j/m^2. This impact stimulus level would be sufficient to initiate almost any dry explosive. Liquid explosives, such as the surface layer melted inside the item, are even more sensitive, although the moisture content from the condensed steam should have a desensitizing effect. Based on the above discussion, we would expect an operator to be able to initiate the explosive inside an item if he were emotional enough. Most of the time, the lance would impact the explosive directly, providing some cushioning effect, but it is judged that about one time in every twenty, the lance will impact onto a relatively thin layer of explosive covering internal metal parts of the munitions item. These situations are the ones that are likely to result in an explosion.

Frequency Estimate

Component Description	Probability
Lance Operator with emotional problem	1 time/year
Operator thrusts lance into item	0.1
Lance tip impacts explosive at internal metal part	.05
Initiation results from impact	1.0

Frequency = 5×10^{-3}/ year

It should be noted that when operational distractions, operator enthusiasm to get the job done quickly, etc. are considered, the scenario frequency could be considerably worse. In this case a frequency of 5×10^{-5}/year may be overly optimistic.

Impeller Impacts/Friction Within Melt Kettle or Separator Vessel

Expected frequency = 2.22×10^{-3}/year

Discussion

A number of scenarios have been identified involving impacts/friction of the impeller against the vessel wall or a foreign piece of metal. In order of decreasing probability of occurrence, the specific failures causing the incidents are as follows:

- due to impeller shaft connection failure
- due to failure of screen above separator (foreign piece enters
- due to excessively worn stuffing box for impeller shaft
- due to impeller not secured well after major maintenance
- due to cover not being aligned properly after major maintenance
- due to impeller shaft being bent after major maintenance

In order to evaluate this potential hazard, it was recognized that all of the energy available for initiation must come from the impeller drive motor. Thus, the "worst case" limit for frictional initiation is the motor power rating 1 hp (746 j/s) for the separator and 10 hp (7457 j/s) for the melt kettle.

Consider the potential for frictional initiation in the separator vessel first. The separator impeller rotates at a maximum of 1 RPM. This corresponds to a tip speed of 0.072 m/s. If we assume that 10% of the motor power goes into frictional heating (i.e. most of the power will be used up in agitating the fluid), then about 75 j/s will be dissipated at 0.072 m/s. Typical kinetic friction factors for greasy steel on steel are on the order of 0.1 (Ref. Marks Handbook). This should be appropriate for a steel impeller rubbing on a steel vessel wall with the liquid explosive acting as a lubricant. The associated normal force is given by

$$N = \frac{75\ \text{j/s}}{(0.072\text{m/s})(0.1)} = 10^4\ \text{nt}$$

Based on the geometry it is estimated that rubbing will occur over a 0.1 cm^2 contact area. Thus, the friction stimulus can be described as $10^9 nt/m^2$ at 0.072 m/s. This corresponds to an initiation probability of approximately 0.1, extrapolating from HBX-1 data presented in Reference 1 (Hercules data in the Battelle report)*.

Impact tests conducted at IITRI (Ref. 5) and elsewhere, indicate that the impact typically occurs over a 10 to 100μs pulse. If the energy is dissipated over a 100μs pulse, the impact stimulus is estimated to be

$$e = \frac{(75\ j/s)(100 \times 10^{-6})}{10^{-5}\ m^2} = 750\ j/m^2$$

This corresponds to a negligible initiation probability for HBX-1.

Even if a factor is applied to account for increased sensitivity of liquid versus solid explosive and if the total motor power rather than 10 percent is taken, the probability rises only to about 0.2.

The melt kettle will operate at 25 or 50 RPM --25 RPM (1.8 m/s) will be assumed for calculations. If we assume 10 percent of the motor power goes into friction, about 746 j/s will be dissipated at 1.8 m/s. The associated normal force is estimated, as before

$$\frac{N}{A} = \frac{746\ j/s}{(1.8\ m/s)(0.1)(10^{-5} m^2)} = 4.14 \times 10^8\ nt/m^2$$

Data for HBX-1 (Ref. 5) indicates a probability of initiation of about 0.012 (at 1.219 m/s).

Impact over a 100μs pulse and a 0.1 cm^2 area in the melt kettle is estimated from

$$e = \frac{(746\ j/s)(100 \times 10^{-6} s)}{10^{-5}\ m^2} = 7460\ j/m^2$$

corresponding to an initiation probability of about 3×10^{-4} for HBX-1. More conservative (limiting) assumptions (all of motor power with liquid explosive) yield a probability of nearly 1.0 in this case.

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*HBX-1 data is used because the initiation probabilities for this material were found to be highest of the materials considered.

Based on the above estimates, an initiation probability of 0.1 is assumed for the separator and 0.012 is assumed for the melt kettle. These were the highest values calculated without making overly conservative assumptions. It must be noted that considerable uncertainty exists in these estimates and it is not clear whether the values assumed are indeed conservative. It also seems that the melt kettle should be more susceptable to initiation due to its higher motor power and impeller velocity, but this over simplified approach indicates that the separator is more hazardous.

Examples of Frequency Estimate for Highest Probability Scenarios

A - Due to impeller shaft connection failure ---

Component**	Description	Probability
403 or 288	Impeller shaft Connection Fails (structural integrity)	5.34×10^{-6}/hr
402 or 287	Loosened Shaft Strikes/rubs vessel wall	1.0
390 or 276	Impact/Friction Stimulus Causes Initiation	0.1(separator)[2] 0.012(melt kettle)

Frequency = 2.22×10^{-3}/yr for separator

Frequency = 2.67×10^{-4}/yr for melt kettle

B - Due to impeller not secured well after major maintenance ---

Component	Description	Probability
289 or 404	Maintenance is required resulting in impeller disassembly*	5.2×10^{-5}/hr
290 or 405	Impeller is not securely refastened	0.003
290 or 406	Impeller loosens during operation	1.0 (assumed)
287 or 402	Loosened Impeller Impacts/Scrapes Wall	1.0 (assumed)
276 or 390	Impact/Friction from impeller striking wall causes initiation	0.1 (separator) 0.012 (melt kettle)

Frequency = 6.5×10^{-5}/yr for separator

Frequency = 7.8×10^{-6}/yr for melt kettle

*Major maintenance assumed once every 6 months and 1/10 of the time requires impeller disassembly.

** Component numbers correspond to numbers on fault tress in Volume 2.

Tool Dropped Into Melt Kettle or Separator During Major Maintenance (Impact Initiation)

Expected Frequency = 2.17 x 10^{-3}/year

Discussion

If a tool is dropped into a vessel during maintenance operations the stimulus level is given by the energy of the tool at the moment of impact distributed over the impact area, or

$$e = \frac{mgh}{A}$$

where m is the mass of the tool, g is the gravitational acceleration, h is the height of the drop, and A is the impact area. If the tool is 1/2 lb (0.227 Kg), is dropped from a height of 1 meter, and impacts over an area of 0.1 cm x 0.1 cm (10^{-6} m^2) the stimulus level will be about 2.2 x $10^6 \frac{j}{m^2}$. If the impact is distributed over a larger area (on the order of 1/8 inch squared) the stimulus level would be about an order of magnitude less. In either case however, according to data for HBX-1 in Reference 5, the probability of initiation would be about 1 (i.e. initiation would occur).

Major maintenance requiring removal of the vessel cover is assumed to occur once every 6 months. The probability of a person dropping a tool or metal item during the maintenance is about 0.01. The probability that a significant amount of energetic material remains in the vessel and the tool or metal part hits the layer is taken as about .01 to 0.1. The basic components of this scenario are summarized below.

Frequency Estimate

Component		Description	Probability
Separator	Melt Kettle		
315	420	Major maintenance is required	5.21 x 10^{-4}/hour
316	421	Tool or part dropped into vessel	0.01
317	422	Significant quantity of material present	0.1
318	423	Impact stimulus causes initiation	1.0

Estimated Frequency = 2.17 x 10^{-3}/year

Rotoclone Fire

Expected Frequency = 2.17×10^{-3}/year

Discussion

The walls inside the ductwork leading from fume collection points to the Rotoclone cleaner(water scrubber) are expected to become heavily contaminated with explosive dust. The time for the buildup to occur must be determined during the operation of the plant, but based on operations of similar systems in the past, the buildup may occur quite rapidly. A Navy Hazards Analysis*** of the North Tower indicated that "the explosive buildup from fumes inside the ductwork will probably be about 1/2 inch after two or three weeks of operation" based on experience, within the ductwork leading to the Rotoclone, initiation during operation should be quite unlikely since there are no moving parts. During cleanup/maintenance of the ductwork initiation by dropping a tool or person ESD (e.g. ungrounded shoes) is possible. If maintenance occurs once every six months and an explosive layer is present in the duct at that time, the probability of initiation by dropping a tool is expected to be about 2.17×10^{-3}/year. The probability of initiation by ESD would be quite small (about 2.3×10^{-5}/year). Incidents while cleaning the ducts can be avoided by more frequency cleaning (i.e. to prevent the layer from getting thick) and by attaching tools to the operators arm with a short cord to minimize the dropping problem.

If the Rotoclone scrubber operates inefficiently for a long period of time, a layer of explosive dust could buildup downstream of the water spray. Then if a bearing overheats (e.g. if overgreased as warned in the Installation, Operating, and Maintenance Instructions, or if the bearing becomes contaminated, or if the V-belt is too tight) the layer could become ignited during operation. This scenario is evaluated below and found to be much less likely:

FREQUENCY ESTIMATE:

Component	Description	Probability
689	Rotoclone exhauster not inspected/ cleaned frequently enough*	2.96×10^{-5}/hr
693	Excess grease put into bearings**	3.85×10^{-5}
698	Bearing temperature rise causes initiation	1.0 (assumed)
	Frequency = 4.7×10^{-6}/year	

*Inspected once per month within a human error probability of .01

** Greased once every 6 months with an error rate of 0.01 and overheat lasting about 8 hours (assumed)

***"Hazards Analysis Report on Washout/Steamout System of Western Demilitarization Facility, Hawthorne, Nevada," by Naval Sea Systems Command (NAVAMPROENGCEN) Naval Weapons Support Center, Crane, Indiana, March 1980.

Rough Handling of Separator Dipstick

Expected Frequency = 1.82×10^{-3}/year

Discussion

This scenario is characterized (for quantification purposes) by the specific case where the dipstick is substantially contaminated with explosive and becomes frozen in its holder. The dipstick is then tapped with a tool to loosen it. This stimulus is considered to be roughly equivalent to dropping a 1 lb (0.454 kg) weight from a height of 6 inches (15.24 cm) with an impact area of 1/4 inch x 1/8 inch (0.19 cm^2). In reality the impact may be spread over a wider area in this scenario, so the assumed area could be quite conservative. This impact stimulus level is calculated to be $3.6 \times 10^4 \frac{j}{m^2}$, which corresponds to a probability of initiation for HBX-1 of 0.35 at the 50% confidence level.

Frequency Estimate

Component	Description	Probability
295	Graduated dipstick becomes badly contaminated with explosive	1.0
296	Dipstick sticks in holder due to contaminant	0.0125/hr
297	Operator rough handles dipstick	0.001
298	Impact stimulus causes initiation	0.35
299	Reaction propagates to bulk of explosive inside separator	0.1*(subjective)

*expected to be high due to narrow opening with only a thin layer of explosive or a spark to propagate the reaction into the vessel

Item Impact Scenarios

Expected Frequency = 8.51×10^{-4}/year (by forklift impact/penetration)

Discussion

Several scenarios were identified under the general category of item impacts. These include impacts during jib crane, building crane, and fork lift maneuvers, items being dropped from a jib crane or building crane, and backing the driverless tractor cart into a wall or component.

Although munitions items are qualified by dropping them from tall towers numerous times, the items dropped are new items. Data compiled during the Vietnam war for 750 lb general purpose bombs (Ref. 9) indicates that items in field use have been initiated by rough handling that is significantly less severe than the qualification tests. During a 12 month period, 5 explosions were recorded out of 3005 mishandling incidents. This data would indicate that the probability of explosion per mishandling is about

$$P = \frac{5}{3005} = 1.66 \times 10^{-3}$$

However, this number is considered to be extremely conservative because not all of the mishandlings will have been reported. A more recent study (unreported) conducted at IITRI indicates that the probability should be more on the order of 1.1×10^{-5} per mishandling. This is based on data from 1968 to 1972 during which 3 midhandling explosion incidents were reported out of 9,066,573 items produced. It was assumed that each of these bombs produced were handled about 10 times and that there were 0.003 mishandling per handling (human error probability).

Example Frequency Estimate (Forklift Impact)

Component	Description	Probability
73	Forklift is used to unload items at north tower	1.86 items/hour
74	Forklift is used near items in building	1.0
75	Forklift is inadvertently driven into item	.01
77	Impact stimulus causes initiation	1.1×10^{-5}

Person ESD

Expected Frequency = 8.12×10^{-4}/year

(at any station where there is exposed explosive)

(NOTE: For the plant as a whole-several stations - the expected frequency is about 10^{-2}/year)

Discussion

Each day personnel must get dressed for work. Management controls to assure proper clothing should be well established and strictly enforced. Protective clothing should include fire retarded overalls of a material not susceptible to static charge buildup, and conductive footwear. It is suggested that personnel be required to completely change from street clothing into work clothing at the plant, using a 2 locker system (one locker for street clothes, plus one locker for work clothes). This will minimize the possibility of improper clothing being worn in the plant.

It appears possible that street shoes could slip through such a system, although quite unlikely. A probability of 10^{-3} is assumed for the operator making such an error. This may be extremely conservative, depending on the management controls incorporated. In addition to the operator wearing the wrong shoes, other personnel and the area supervisor would also have to miss the error. On a dry day, an operator wearing ungrounded foot gear could become charged to 15 to 22 mj or higher energies. Such energy levels have appeared in numberous articles throughout the literature (e.g. Reference 7). This corresponds to an initiation probability of .05 to 0.1 for HBX-1.

Example Frequency Estimate

Component	Description	Probability
109	Operator assembles adaptor/seal plate at assembly table or tilt table	1.86/hr
110	This operator wears ungrounded shoes in the area	.001
111	Area supervisor does not stop him	0.5
112	Other personnel do not stop him	0.7
113	Operator becomes charged (fraction of dry days in year)	0.3
114	Operator discharges to open item (most likely will discharge to grounded metal elsewhere)	0.1
115	Discharge is to exposed explosive in item	0.1
116	ESD energy causes initiation of item	0.1

Impingement of Viscous Explosive Onto Grate to Separator After Line Unblocks

Estimated Frequency = 7.66 x 10^{-4}/year

Discussion

In the North Tower of the Washout/Steamout Building, a flexible drain hose is connected between each tilt table and the piping that drains into the separator vessel. From time to time, this hose will be changed either to accomodate new items and new tilt angles or merely to replace an aged hose. If the replacement hose is too long for the tilt angle to be used, the hose may dip creating a low point in the line. Explosive will tend to stagnate at the low point, solidify near the wall (the wall is not steam jacketed) and eventually block the flow in the line. This is a potential problem particularly for the highly viscous explosives to be processed (H6 and HBX, which fill 31 of the 47 items listed for the North Tower in the Batelle Report --Ref. 1, i.e. 66% of the items).

When the line becomes blocked, the slug of solid explosive in the line may eventually be forced out due to the buildup of steam pressure in the cavity in the item. 15 psig pressure represents a force of about 100 lbf, which neglecting viscous drag at the walls of the lines could accelerate the slug of explosive to fairly high velocities by the time it impacts the wall or grate in the inspection box just above the separator. The slug of solid explosive would act as a "hammer" impacting liquid explosive at the grate. Liquid explosive can be more sensitive to impact than solid material. For TNT the impact energy required for initiation drops by a factor of 6 going from 20°C solid to 100°C liquid (Reference 6). In addition compression of captured air bubbles at the impact location may be a factor.

Based on the diameter and length of the drain hose, it was estimated that a 10 kg slug of explosive could impact the grate over a 4.6 x 10^{-4} m^2 area at the velocity that the steam ultimately flows in the drain line (0.64 $\frac{m}{s}$). This yields an impact stimulus level of 4.5 x 10^3 $\frac{j}{m^2}$. Using the Reference 1 Probit curves as the baseline, the associated ignition probability is estimated to be about .0015, accounting for increased sensitivity of the liquid phase.

Frequency Estimate

Component	Description	Probability
140	Steamout operation is being accomplished	1.86 items/hour
154	Liquid explosive is highly viscous	0.66
155	Drain line too long(human error probability)	0.001
174	Line becomes blocked	0.1
177	Line unblocks after slug forms	1.0
178	Ignition due to impingement	0.0015
179	Reaction propagates to bulk of explosive	1.0
233	Deluge in steam lance fails to suppress this reaction	1.0

Impact of Separator or Melt Kettle Cover Onto Vessel Lip During Major Maintenance

Expected Frequency = 2.17×10^{-5}/year

Discussion

This scenario involves impact of the cover of a vessel into the vessel lip during a major maintenance operation. Even when assuming the initiation probability is 1, the frequency is found to be quite small due to the small amount of energetic material present during the maintenace operation.

Example Frequency Estimate

Component	Description	Probability
306	Major maintenance is required involving removal of separator cover	5.21×10^{-4}/hr (abt. once every 6 mos.)
307	Vessel lip is contaminated with explosive	0.1
310	Operator controlling crane causes cover to swing into vessel	0.01(human error)
309	There is a significant amount of material present in the vessel (Material should drain out generally)	0.1
308	Impact onto vessel lip causes initiation (P~1) and the reaction propagates into the vessel (P<0.1)	0.1

Explosion Due to Foamup in Melt Kettle During Vacuum Treatment

Expected Frequency = 8.8×10^{-7}/year

Liquid explosives have a tendency to foam, particularly when subject to vacuum and agitation as in the melt kettles. Foaming is considered to be a possible mechanism for explosive to be pulled into the vacuum system during treatment. If in addition, pump seal water is lost, an ignition source could be present at the pump. This is a low prob ability event because of the safety interlock on the seal water and could be eliminated altogether with a vacuum trap in the line to the pump.

Frequency Estimate

Component	Description	Probability
427	Explosive is susceptable to foaming	1.0
424	Explosive foam is pulled into vacuum system and reaches pumps*	4.38×10^{-3}
429	Explosive gets into pump moving parts**	1.0 (assumed)
444	Manual water supply valve for pump is closed	0.01
442	Water pressure interlock fails to stop vacuum pump	4.823×10^{-6}/hour
457	Ignition occurs at vacuum pump due to loss of water (friction at vanes or bearing overheat)	1.0 (assumed)

*Foaming is expected to occur frequently but it is not expected that the foam level will reach the vacuum port unless the vessel is overfilled. Melt kettles will be filled about 6 or 7 times a day. At an error rate of 0.01, overfilling may occur about 4.38×10^{-3}/hour, and explosive may remain in the line for about 1 hour thereafter ($P=4.38 \times 10^{-3}$)

**Here it is assumed that no vacuum trap is in the line.

ESD - Metal Piece is Molded Into the Explosive Inside an Item and Charged Up During Steamout

Expected Frequency = very low

Discussion (Reference Appendix A for Methodology)

For this scenario the primary unknown is the leakage resistance for the path from the metal piece along the explosive surface to the grounded metal casing of the item. From discussions with personnel involved in making electrical measurements, it is anticipated that for moist or dry explosive the resistance should be essentially open circuit, or at least tens of megohms. There is expected to be a significant decrease in the resistance as the surface becomes moist during steamout but the resistance will still be quite high. If we view the "moist" conduction path as a thin film of water (bulk conductivity of 10^{-6} mho/cm) the resistance of a micron thick layer would be about $10^9\Omega$. For a 10 micron layer it would be $10^8\Omega$, and if the water layer were 0.01 cm (100μ) it would be $10^7 (10M\Omega)$. Surface resistivities for a number of materials at 30% and 90% Relative Humidity is presented in reference 2. The comparison for several materials is presented below:

Surface Resistivities σ (ohms)*

Material	at 30 R.H.	at 90 R.H.
Paraffin	10^{16}	5×10^{15}
New American Hard Rubber	5×10^{15}	10^9
Sealing Wax	3.16×10^{15}	0.0795×10^{15}
Beewax	0.63×10^{15}	0.63×10^{15}
Celluloid	79.5×10^9	1.26×10^9
Ivory	15.9×10^9	3.16×10^7
Slate	0.159×10^9	10^7

*note $R = \sigma \frac{l}{W}$ where l is the path length and W is the path width. If $\frac{l}{W} \approx 1$, $R = \sigma$.

The 90% RH values are expected to have higher resistivities than would exist inside the item because a liquid layer will be present in the item. In order to bracket the problem, for the "moist" case we assume that the leakage path resistance will be about $10^7\Omega$. For the dry case, the data shown above indicates that the resistance could approach $10^{16}\Omega$, although this is probably optimistic (i.e. too low a value).

Charging Current

As will be done for the "unbonded adaptor" scenario later in this appendix the total rate of charge transfer from the lance is taken as the total steam flow rate at a charge density of 10^{-6} coul/Kg. The total charging current is then 4.15 X 10^{-9} coul/sec. Not all of this will inpinge on the metal piece molded into the explosive. If the metal piece is about 1 inch (2.54 cm) in diameter and the lance is 4 to 6 inches (10-15 cm) from the piece, by geometry only about 1/100 of the charge will impinge on the piece. Therefore, the charging current i_{in} is taken as 4.15 X 10^{-11} coul/sec.

Capacitance of the Metal Piece

If we assume the metal piece is about 1 inch (2.54 cm) in diameter, and well away from the metal walls of the item, it has been shown that the capacitance will be about 1.4 x 10^{-12} f (see Appendix A).

Application of Circuit Model

The maximum voltage attained by the metal piece is given by

$$V = i_{in}R$$

For the "moist" case R is taken as $10^7\Omega$. This yields a voltage of 4.16 x 10^{-4} volts and an associated energy of 1.2 X 10^{-19} joules. Clearly, in this case the voltages and associated energy levels should not be a problem.

For the dry explosive, we assume the resistivity will approach $10^{16}\Omega$. This drastically changes the situation in that the computed maximum voltage now becomes 4.16 x 10^5 volts. This corresponds to an energy of 0.12 joules. For HBX-1 the probability of initiation by an electric spark of that energy is in the range 0.5 to 0.84. In the item, the explosive will be hot, tending to increase this probability, but water will be present tending to decrease the value.

However, this is the maximum possible energy attainable at the metal piece. It would take time to build up to that level, the time being the RC time constant. To approach the maximum level would require 3.9 hours, and by that time the surfaces would be moist. The surfaces should be moist within minutes of steaming. The energy at the metal piece would grow by the following relation:

$$e = \frac{1}{2} CV^2$$

$$\text{where } V = i_{in}R\,(1 - e^{-\frac{t}{RC}})$$

After one minute the energy would only be 2.2×10^{-6}j (HBX-1 ignition probability would be negligable). After 5 minutes the energy would grow to about 5.5×10^{-5} joules, again corresponding to a negligible probability for HBX-1. These later cases are more likely to represent the hazard than the maximum possible energy noted earlier.

ESD - Metal Piece Dropped Into Box on Weigher

Estimated Frequency = very low

Discussion

This scenario considers a metal item being dropped into a box during filling at the flaker and becoming electrically charged as the flakes fall onto it. The boxes being filled will contain 55 lb (25 kg) of flaked explosive. As discussed in Appendix A, materials such as TNT in controlled chuting experiments become charged to about 10^{-5} coul/kg in the worst case (only 2.1 X 10^{-7} coul/kg for TNT itself). Only a small fraction of the flakes will contact the metal piece and charge it. By geometry, it is estimated that only about 0.001 of the flakes will interact with the metal piece. Thus the total charge on the piece will be about

$$Q = (10^{-5} \frac{\text{coul}}{\text{kg}}) (25\text{kg})(.001) = 2.5 \text{ X } 10^{-7} \text{ coul}$$

The capacitance of a 2.54 cm (1 inch) diameter piece of metal will be about 1.4×10^{-12} f. TNT in bulk has a resistivity of 9×10^{8} ohm-m. This would indicate that the leakage resistance will be about 10^{10} ohms; however, the flake form of the TNT and the presence of the packaging materials should increase the resistance significantly. It is expected that the resistance could reach 10^{16} ohms, based on surface resistivity of dry flakes, and this value is used to assure conservatism.

Thus, the maximum voltage of the metal piece should be about

$$V_{max} = \frac{Q}{C} = \frac{2.5 \times 10^{-7} \text{ coul}}{1.4 \times 10^{-12} \text{f}} = 1.79 \times 10^{5} \text{V}$$

In reality the characteristic time for charging (RC) will be quite large (233 minutes). It takes about 2.5 minutes to fill a box, so only about 1 minute at most will be available for charging.

ESD - Poor Electrical Contact at Lance Adaptor.
Voltage Builds Across GAP

Expected frequency = very low

NOTE: It would be extremely difficult to lose electrical bonding by any chain of events.

a) if a non conductive rubber replacement gasket is used, bolts are still used to connect the adaptor to the mine. The bolts will make a good electrical connection at that end. Loss of bonding in this way is not considered to be credible.

b) if the flange to the lance holder is allowed to become extremely dirty, it is possible that loss of bonding will occur. Again this is unlikely because the flange faces are a metal to metal contact and the v-retainer ring is another metal to metal bonding vehicle. This mechanism is taken to be credible, however.

Resistance

Based on measurements made by IITRI personnel in prior projects a 10 ohm resistance across a "poor contact" is reasonable. To check this, a calculation was conducted assuming a 0.05cm gap over a 240 cm^2 flange area. For poor bulk conductivity materials (e.g. styrofoam and teflon) the resistivity can be as high as 10^{18} ohm-cm. Thus,

$$R = \rho\frac{\ell}{A} = (10^{18})(\frac{.05}{240}) = 2.1 \times 10^{14}\Omega$$

If the gap were filled with water (ρ=10^6 ohm cm) the resistance would be about 210Ω. If it were filled with a metal oxide (copper oxide has $\rho \sim 10^5$ohm cm) the resistance would be more like 21Ω. It is felt that a resistance of about 10-20Ω would be most realistic. A value of 20Ω was selected for calculations.

Capacitance

The capacitance of the flange was estimated assuming the dielectric constant is about 10.

$$C = \frac{\varepsilon_o kA}{\ell} = \frac{(8.85 \times 10^{-12})\ (10)\ (0.024)}{.0005} = 4.25 \times 10^{-9} f$$

Charging Rate

To estimate the charging rate, the larger charge per unit mass (Q/M) value for water sprays presented in Appendix A was assumed to be correct, that is 10^{-6} coul/Kg.

The voltage after a minute is given by

$$V = V_{max} (1 - e^{-t/Rc})$$

$$= 1.79 \times 10^5 V (1 - e^{-\frac{1}{233}}) = 766 V$$

The associated energy is then given by

$$e = \frac{1}{2} CV^2 = \frac{1}{2} (1.4 \times 10^{-} f) (766V)^2$$

$$= 4.1 \times 10^{-7} j$$

The probability of initiation by a spark of this energy level is negligible. The total steam rate per item is 33 lb/hour (Reference 1) or 4.16×10^{-3} Kg/sec. If it is assumed that all the steam acts as a charge carrier for this scenario, the charging rate is computed to be 4.15×10^{-6} coul/sec.

Estimates to Characterize the ESD Hazard

Several quantities can be calculated based on the parameter above in order to characterize the hazard potential. First, the maximum voltage that is possible across the gap is limited by the breakdown electric field strength $E_B = 3 \times 10^6 \frac{V}{m}$, and by the maximum charge given by the circuit model in Appendix A. The breakdown field limits the voltage across the gap in the following way:

$$V = E_B \circ (\text{gap})$$

$$= (3 \times 10^6 \frac{V}{m}) (.0005m) = 1500 V$$

The circuit model gives the voltage as

$$V = i_{in}R$$

$$= (4.16 \times 10^{-9} \frac{coul}{sec}) (20\Omega) = 8.32 \times 10^{-8} V$$

The circuit model indicates that a negligible voltage can develop across the gap. A spark would not occur, and if a spark could occur, the associated energy is given by

$$e = \tfrac{1}{2}CV^2$$

$$= \tfrac{1}{2}(4.25 \times 10^{-9}) (8.32 \times 10^{-8})^2$$

$$= 1.5 \times 10^{-23} j$$

which is a negligible value. Even if the resistance across the gap were several orders of magnitude higher the voltage and associated energy would be too small to pose a hazard.

APPENDIX E

SUMMARY OF ACCIDENT REPORTS FROM DDESB FILE

(extracted from Final Report for ARRADCOM Contract DAAK10-78-C-0029, "Development of a Hazard Classification Procedure for Inprocess Propellant and Explosive Materials" by H.S. Napadensky and R. Pape, November 1979)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MELT-POUR CASTING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
395	Amatol 60/40	150	0/0	Melting Process-cascade	Fire		Spontaneous ignition at lower sieve-impurities-thermal
433	15% Aluminum, 15% Hexogen 70% TNT	18,000 + 116,000		Melt-pour Facility	Explosion	300/-	1) Thermal: improper temperaure control of kettle contents
8	Scaling wax, H.E. antiair-craft projec-tiles		0/2	Melting Operation	Fire-Explosion		Unknown, no specification
41	Molten TNT	11,000-14,000	9/16	Dopp Kettle Feeder Fa 2000 lb bombs	Explosion		Unknown
116	TNT	110,000	8/1	Casting/cooling Shed	Explosion		1) Friction 2) Impact
140	Molten TNT (81 mm mortar)	2000	13/27	Melt-pour Operation	Explosion		1) Impact (or TNT dust) 2) Dust or vapor ignition inside melt hood-thermal
141	TNT Melt		22/84	Continuous Melt Unit	Explosion	300-400/-	1) Friction 2) Pinching
191A	Amatol Mixture 50/50 (TNT-Ammonia Nitrate)		66/23	Pouring molten TNT into shells	Explosion		Unknown
235	TNT	10		Melt kettle	Fire		Thermal-steam line to kettle overheated
297	TNT 1. crude 2. processed 3. finished	28 tons 28 tons 28 tons	75/119	Melting	Fire-Explosion		Unknown, no specification
813	Experimental propellant		1/1	Casting pro-pellant	Explosion-Fire		Friction-propellant shaft pocking system inade-quately designed
1099	Cyclotol 70% RDX, 30% TNT		2/?	Melt Pour Operation	Explosion		Unknown, not legible
1122	Lead Styphnate	2 kg	1/0	Pouring Operation	Explosion		Unknown, no specification
1332	Cyclotol	4000-5000	0/1	Melt Pour Building	Explosion		Unknown, no specification

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MELT-POUR CASTING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
386-19	Picric Acid			Melt Pot	Fire		Spontaneous ignition of vapor-thermal (?)
386-20	Picric Acid			Melt Pot	Fire		Spontaneous ignition of vapor-thermal (?)
386-21	Picric Acid			Melt Pot	Fire		Spontaneous ignition of vapor-thermal (?)
1275	TNT		0/0	Melt Tank	Fire		Friction/spark initiation during removal of old (TNT) contaminated insulation (maintenance)
518	RDX/TNT (6) torpedoes		11/	Melting Process	1) Bomb 2) Fire-Explosion	500 yrd proximity completely destroyed	Foreign material inclusion; cardboard soaked with oil caught fire during melting (fuel & thermal)
601	Lead Azide	1) 10 gr detonator	0/1	Unloading molds from extraction unit	Explosion	5-10'/--	Invested mold was brought in contact with surplus explosive on top of the extraction machine
906	TNT	Residual TNT contaminate	0/0	Melt reservoir	Fire	NA	Impact of contaminated bottom of tank; residual TNT on bottom exposed to 200°F for 9 hours
1066	1) 4-Polaris A3 second stage 2) Nitro-gylcerine 3) Casting powder 4) Scrap casting solvent 5) Aspirator	-- 4800 865 250 30	3/11	Prop. motor casting	Explosion	1500/2000	Solvent handling - vapor initiation
989	Pentolite (50/50)	/20	0/0	Melt tank	Explosion & Fire	100/0	Instability of Pentolite under prolonged heating

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MELT-POUR CASTING (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE	PROBABLE CAUSES
868	TNT	Residual TNT on floor	0/1	Melt chamber	Fire		Friction initiation due to scraping of dry TNT residual on concrete floor with steel spatula
1230	Cyclotol		6/4	Melt and pour operation	Explosion-Fire		1) Spark initiated - tool droppage 2) Riser scrap causing friction between agitator and kettle 3) Foreign material present-friction 4) Contamination of electrical controls with explosive dust, etc.

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN TOTE BINS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1225	RD 13-33 NOL Prinec 130 Dextrolead Azide	105	2/0	Service Supply Powder Buggy	Explosion	483/	Impact-dropped NOL 130 into buggy

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN HOPPERS

ASESB NO	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
359	Not specified	500	5/0	Hopper of Screw Filling Machine	Explosion		Friction (foreign object in hopper)
1273	Gilsonite, sulfur, aluminum fires		0/2	Charging/Loading Feed Hopper	Fire		Unknown
364	Amatol 80/20	75	3/1	Hopper/Screw Filling Operation for Extrusion	Explosion	300/-	Friction (foreign object or solid sensitized Amatol in feed)
608	5 grain A-Z detonators		0/2	Delivery Chute of Filling Machine	Explosion		Friction from tapping disrupting blockage in chute
636	6 grain ZY detonators (Lead Azide and CE)		0/0	Feed Hopper of Filling Machine			Friction between guide plate and charge plate
1547	C-4			Hopper Dump Operation	Explosion		Unknown-no specification
1598	Primer		0/0	Syntron Primer Hopper Dump Phase	Explosion		Unknown-no specification
120	Smokeless Powder	4000	1/0	Filling Feed Hopper in Screen House	Fire-Low Order Detonation		Impact-mechanical failure of hopper
234	Smokeless Powder		3/0	Chute for/Solvent Recovery Process	Explosion		1) Friction - during trembling impingement 2) ESD
1168	NIBEX-High Energy Propellant (Zirconiom)	150	0/3	Dumping into Hopper	Fire-Explosion		1) Impact 2) ESD
334(e)	Black Powder			Supply Hopper Filling Operation for Pelleting Machine	Explosion		Friction
1296	Multi-perforated single base propellant	1900-7000	2/4	Drop Plug Buggy/ Hopper Removal Proposed	Fire-Explosion		1) ESD 2) Impact

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN HOPPERS (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
499	Smokeless Powder 40 mm cannon		3/13	Feed Hopper in Blending Operation	Fire		1) Friction 2) Impact
592	Nitro-glycerine			Hopper/Buggy in Mix House			Unknown-no specification
747	Mercury Fulminate Potassium Chlorate Antimony Sulfide, Sulfur, Sealed Powder		0/1	Filling Hopper Supply	Explosion		Friction
824	Photoflash Composition for 762 mm Rockets		0/0	Hopper Feed Chute	Explosion		1) Impact (foreign body) 2) Friction (from dump gate valve assembly a foreign particle)
1011	Giant Gel 40% Dope, Sulfur		0/0	Feed Hopper/Weigh Station	Flash Ignition		1) Impact 2) Friction hard aluminum and steel interface 3) Air dust mixture-friction
569	Smokeless Powder	130,000	9/0	Filling Bin	Fire		1) Friction-metal-metal contact by opening slide date on car 2) ESD
755	Multi-perforated single base M10 cannon powder and graphite dust	3000 and additional 2000	2/3	Loading pre-blender hopper	Explosion-Fire	900/4500	1) Static discharge-due to powder impingement 2) Potential difference between accumulated static charge of powder in buggy and the powder in metal barrel 3) Potential difference between operator and powder 4) Friction between hopper edge and buggy

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING RECRYSTALLIZATION

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
124	RDX	15	0/2	Recrystallization Process	Explosion		1) Impact 2) Hot Spot - Temperature 3) Friction (metal-metal)
386-6	Picric Acid			Crystallizing Process	Fire		Friction
1222	RDX Slurry		0/1	Valve for re-crystallization still	Explosion		Impact, unplugging of valve with nonsparking screw driver

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING NEUTRALIZING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
121	Nitro-glycerine	7557	1/9	Neutralizing House	Explosion	-/400	1) Impact 2) ESD
290	Nitro-glycerine	3700	6/0	Neutralizer House/Plug Valve Opening Process	Explosion		1) ESD 2) Electrical 3) Friction/Impact - Mechanical Equipment

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING GLAZING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
[illegible]41	Detonite	9000		Glazing Facility	Explosion	1500-5000/ 2 miles	Unknown
90	Black Powder		0/0	Glazing Mill	Explosion	300-600/	Electrical (lighting)
194	Black Powder	875,000	24/34	Glaze-Pack House	Explosion-Fire	Structural Damage to 4,000 ft	Unknown - No specification
741	Ball Powder WC870	1060	1/- (Burn)	Salt coat and glazing; Sweetie barrel	Explosion	Immediate area	Slurry spillage-alcohol fumes ignited by metal-metal contact (bucket and object)
41	Black Powder	5000	0/0	Glazing	Explosion	850 ft/1½ miles	Lightning
1330	1) Semi-finished black powder 2) Finished black powder	7000 1300	1/1	Glazing	Explosion	½ mile/2 miles	Unknown

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PUMPING OPERATIONS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
407	TNT (liquid)	11,000	2/3	Pumping TNT from fortifier	Explosion		1) Friction 2) Impact } Overheated pump caused by impeller-casing interaction
342-27	Not specified			Piping/continuous melt operation	Explosion		Unknown, no specification
1304	RDX/TNT swarf	3		Vacuum pump	Fire	NA	Pump overheating
1032	HMX slurry		0/0	Pump	Explosion		a) HMX caking within pump cavity caused friction b) Presence of supersensitive Alpha fumes of HMX
1052	DNT/TNT (70-30%)		0/0	"Downie" pump	Fire	NA	1) Localized overheating within pipe casing 2) Foreign objects
1280	Propellant Single base		0/0	Slurry delivery pipeline	Explosion-Fire	250/-	Thermal decomposition due to heat application from steam tracer line and propellant accumulation within pipe

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN BELT CONVEYORS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
625	4.2 in Mortar		0/4	Belt Conveyor loading line during removal of shell	Explosion		Impact on firing pin
1214	M406 40 mm Rd: Comp B and Comp A5	32 g		Belt Conveyor/ Assembly	Explosion		Defective freeze
1302	Primer Electric 52, Lead Styphnate, Graphite Potassium, Chloride Barium Nitrate		0/5	Belt Conveyor loading filling line	Explosion-Fire		Friction
593	Nitroglycerine				Explosion	/750	Friction: wood scraper and compound

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN SCREW CONVEYOR TYPE

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
812	Rakrift Explosion (Nitroglycerine and Nitroglycol)	200	4/15	Feeder Extruder Screws	Explosion		1) Impact 2) Friction (metal-mold)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN PNEUMATIC CONVEYOR

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
1314	Commercial Powder	Total 8210 (12,000 lbs/hr)	0/6	Air-conveying of powder for reblender	Explosion	Immediate building 82/-	1) Friction heat buildup of particles inside rubber hose (deterioration of hose) 2) Extreme velocities of transfer

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN FILTERS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
1683	6 amino-penicillanic acid S-oxide (trimeric acetone peroxide exploded)		0/1	Filter/Reactor	Explosion		1) Friction-technician touched filter cake with steel spatula 2) ESD - tests show explosion occurs at 11.5 mJ electric spark
1182	Chemical filter solution Mithanol (50-50) and 5% caustic		0/0	Decontamination/ Cleaning	Explosion/Fire		Fuel-Air Ignition: 1) Friction 2) ESD 3) Heat and reaction thermochemical

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING SEPARATION OPERATIONS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
460	Nitroglyc-erin	3800	2/1	Nitration Process/ Separator Phase	Explosion	400-600/2 miles	Thermochemical reaction, decomposition of nitroglycerine
263	Di and Tri-Nitrotoluene			Separation pro-cess/scooping material residue for further pro-cessing (wash)			1) Friction } Dropped article 2) Impact } into container 3) Incompatible material
1109	Nitrated sugar glycerine	400		Separator	Explosion	1920/-	Thermochemical decomposition

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DISTILLATIONS OPERATIONS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
1019	Di-nitro fluourethane (Daphne)	20.75	1/2	Experimental nitration/ distillation process	Explosion		Sudden oxidation (admission of air to reduce vacuum without first cooling)
1091	Butadiene			Distillation column-leaky seal on pump	Fire		Fuel-air vapor ignited by open flame
1190	Ball Powder and Solvents		0/8	Distillation Process	Fire		No specification (guess-overheat and no agitation)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN A MILL

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
1130	Ballistite/50% Nitroglycerine	20 kg	1/2	Rolling Mill	Fire		Friction-foreign object
1073	M-5 Propellant; Cellulose water, Alcohol, wet Nitrocotton	130	0/2	Block Breaking Operation	Explosion		1) Pinching (broken belt entering process equipment)(fuel-air explosion possible) 2) Friction-blade impacting
391	Ammonium Perchlorate	1000	3/0	Crushing/Grinding Mill	Fire		1) Friction } foreign 2) Impact } particles
530	Potassium Perchlorate	125+125	1/0	Grinding Operation	Explosion-Fire	90/-	Hot spot from electric drive motor and contamination
606	Black powder	Tons	13/17	Granulation Section	Explosion		Friction
632	Igniter Pre-mix; Barium Peroxide, Zinc Stearate, Red Toner		1/7	Ball Mill	Explosion		Chemical decomposition/ unstable peroxide and moisture
1039	X-8 Propellant		0/0	Receiving Trough/ Rolling Operation	Fire		1) Friction 2) Contamination
685	Black Powder	1600	4/0	Wheel Mill	Explosion	400-750/5 miles	Unknown, no specification
940	Zerconium, Lead Dioxide, Binder, Igniter	300 g	0/2	Grinding/Mortar and Pestle	Flash Explosion		1) ESD } impact sensitivity>140 cm 2) Friction } temp of explosive >250°C
1607	Black Powder (rework, low nitrate fuze powder)		1/3	Milling Operation	Explosion		Friction scraping solidified explosive
1116	Phyto-pharmaceutical powder composition			Grinding/Filtering			1) Mechanical friction 2) ESD 3) Electrical spark
91	Rifle Powder	400	0/0	Wheel Mill Operation	Explosion		Friction-plough in contact with bed plate causing increase of heat

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN A MILL (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
189	Black Powder	3000	0/0	Corning Mill Building	Explosion		1) ESD 2) Friction (bearing machine parts) 3) Foreign material in mix
202	Magnesium	100	0/0	Hammer Mill	Fire		Electrical-from lightning
548	Black Powder	500	0/0	Wheel Mill	Explosion		Unknown, no specification
771	Sodium Nitrate-Black Powder	805	1/0	Wheel Mill	Explosion		Unknown, no specification
867	Gun Powder	330	1/0	Granulating Roller Machine	Explosion		Unknown, no specification
649	Black Powder	500	0/0	Corning Mill	Explosion-Fire	1300/1 mile	Friction-foreign metal object between mill rolls ignited dust
781	Sodium Nitrate Black Powder	650	0/0	Wheel Mill	Explosion		Wheel Slippage-Friction
782	Black Fuse Powder	3700	0/0	Corning Mill	Explosion	350/1300 building demolished	Unknown
1277	M13	50	0/0	Stokes <u>Granulator</u>	Fire		1) <u>Friction</u> between agitator and screen 2) Abrasion nature of binding agent due to natural evaporation
1231	Ammonium Percholrate		0/0	Sneco Vibra-Energy Grinding Mill	Explosion		a) Adiabatic air compression b) Localized buildup near flanges } friction c) Foreign particle }
504	Green Charge Mix { Pot. Nit. Charcoal sulphur	312	0/0	Wheel Mill #2	Explosion-Fire	310/intraplant	Unknown

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN A MILL (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
1295	Ammonium Perchlorate		0/0	Raymond Grinder	Explosion	Bay area/ Building	Friction initiation due to contamination of bearing hub oil (hydrocarbon)
1316	N-S Paste Slurry			Expeller Mill	Explosion		Mechanical or chemical initiation(?) Friction
693	Sodium Nitrate Black Powder Composite			Wheel Mill	Explosion	223/-	Friction-too dry powder

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
110	#83 Grenade MKII	--	-/-	Unloading mold	Fire		Friction (pinched explosive between two metal moving surfaces)
365	Explosive "D"	25	?	Press loading into shell	Explosion		Unknown
412	Smoke Composition PN507 (into No. 19 smoke container)		-/-	Pressing operation	Fire-Explosion		Friction (metal-metal contact)
449	Tetryl booster		0/3	Pelleting operation	Explosion		Unknown
484	Black powder	25		Pressing-15 in. horizontal	Explosion		Guess-friction
683	Black powder		1/0	Pressing operation		500/3-1/2 miles	Unknown-no specification
1341	Semi-gelatin dynamite		4/2	Cartridging machine	Explosion	300-400/-	Unknown-no specification
1379	Composition A5		0/0	Remote consolidation press	Explosion		Unknown-no specification
1381	40 mm Illuminating Cartridge		0/1	Consolidation press operation	Explosion		Unknown-no specification
1397(T)	55 gr PBSG-12		2/1	Pressing operation	Explosion		Friction
1407(T)	Composition A5		0/0	Consolidation press	Explosion		Unknown-no specification, guess-friction
1409(T)	Composition A5	81 gr	0/0	Penwalt press	Explosion		Unknown-no specification
1416(T)	Composition A5		0/0	Penwalt press	Explosion		Unknown-no specification
1421	PB-HMX	24 gr	0/0	Stokes pelleting press	Explosion		Friction
1597	Composition A-3	4.1	0/0	Denisson hydraulic press	Explosion		1) Friction (foreign article 2) Pinching cracking during press operation

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
1600	RDX	12	0/1	Cherry barrel Rotary Press (pressing)	Explosion		Equipment failure, (guess friction)
1610	Lead-Azide, Lead Styphnate, Detonator manufacture		0/0	Final press house	Explosion		Unknown, no specification
1648	PEXN		0/0	Booster press cell operation	Explosion		Not clear
1663	Composition A5	10	0/4	Consolidation pressing, multi-station rotary press; Colton model 270-18	Explosion		1) Friction 2) Impact } mechanical equipment failure
1674	Igniter Mix	400 gr	0/2	Compacting/ pressing, Stokes Pelletizer Press	Explosion		Friction
1689	AFX 903 Experimental	53 gr	0/0	Pelletizing, 100 ton hydraulic Ran press	Explosion		Friction (foreign object inclusion)
99&100	Nitroglycerine gun cotton, ammonium nitrate and sodium nitrate		6/12	Press operation	Explosion		Friction (between cylinder wall and ram)
264	Tetryl booster charge		1/6	Pressing	Explosion		Friction (from ram)
320	Dynamite nitroglycerine		3/0	Cartriding/ pressing	Explosion		1) Friction from guide rods 2) Overheated from tester
1192	Flare composition	50	0/1	Pressing operation	Fire-Explosion		Unknown, no specification
1479	MK 48 Mod		0/0	Remote pressing operation	Explosion		1) Friction 2) Impact } mechanical failure
705	Explosive-no specification		0/0	Rotary pelleting press	Explosion		Unknown, no specification

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
709	Alco Pellets for JATO Unit igniters ($KCL_4 + A\ell$)		0/1	Pelleting press	Explosion		Unknown, no specification
710	Black powder		2/2	Pressing operation	Explosion	500-600/1300	Unknown, no specification
722	8.6 grain AZY detonators, A Composition plus Lead Azide		0/1	Pellet extracting machine	Explosion		Friction (surplus material added)
752	Ammonia Gelatin 40%	4200	4/0	Gelatin cartridge house	Explosion	300/2 miles	Unknown, no specification
764	Charge increment for 40mm projectile			Pressing increment Dennison Consolidation press	Explosion		Friction
791	105mm shell (C-4)	7.25	0/0	Remote press-operation at 1527 psi	Explosion		Not determined
812	Rokrift: nitroglycerine and nitroglycerine	200	4/15	Miller Dann cartridging machines	Explosion		<u>Friction</u> (a) screw - container misalignment (b) box - explosive material interface <u>Impact</u> (a) mechanical failure (b) cartridge box dropped
814	Gelatin Dynamite	245		Gelatin cartridging house Starrett Gelatin machine	Explosion	550-650/800	Unknown, no specification
909	Gelatin		4/0	Cartridge machine house		300-750/3/4 mile	Unknown, no specification
918	Potassium Nitrate, Boron Laminac, Composition		0/2	Slugging/compacting	Explosion		Friction (pinching) Impact

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
943	M17 Propellant	90	0/0	Faraguhar Vertical Blocking press (at 2000 psi) 11-3/4" diameter	Explosion		Adiabatic compression, (of vapors)
1016	Flare composition (igniter, fire clay, dry flare) Experimental		0/2	Pressing-Dennison Multipress	Fire		1) Friction/impact 2) Static spark
1063	PBX	2-1/2	0/0	Pelleting-Kur Lehner Single Action Press	Explosion		Impact/friction (mechanical failure of press)
1171	Alco Pellets for Tartar igniters		2/0	Pelleting press	Explosion		Friction (between turning table and wedged end plate)
386-1	Picric Acid			Pressing operation	Ignition		Impact - worker dropped base of mold into picric dust
386-2	Picric Acid			Pressing operation	Flash ignition		Impact
1279	NC		0/6	Dehydration press	Explosion		Friction-caused by misalignment of ram and NC block with liner
677	TNT	1/2	0/3	Plunger-die matrix	Explosion		Die-plunger misalignment causing frictional initiation
679	Tetryl pellet		-/-	KUX pelleting press	Explosion		Frication/impact; misalignment of ram; mechanical malfunction
687	Tetryl pellet		-/-	KUX pelleting press	Explosion		Impact; friction
711	TNT			Press	Explosion-Fire	125/-	Mechanical malfunction; metal-to-metal contact
754	Nitroguanadine green powder area (solvent vapor shot)		0/0	Pre-blocker press	Explosion		1) Autoignition of vapors 2) Impact

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
946	Flake TNT		0/0	300 ton transfer press	Explosion		Friction: 1) Extrusion-side of ram & die wall 2) Impact-ram & fractured die 3) Foreign material 4) Misalignment
1506	Composition A-3	Single Pellet	0/2	Stoke pelleting press	Explosion		1) Foreign material 2) Failure of punch 3) Excessive pressure due to excessive pellet buildup on-ram
1241	M-1 Propellant		0/1	Farguhar vertical blocking press	Fire-Explosion		Compression of entrapped air and solvent vapor causing autoignition (ethyl ether, ethyl alcohol)
802	M7 (solventless)	38		15" R.D. wood	Explosion	141/-	--
718	Matador rework powder (rejected grains)	7 gr		Press	Explosion	20/-	Contamination of seal-line interface in die assy. Ram was stationary press-gate and die-assy as the focal point of detonation; compression of heel on 7 grain charge initiation possibility
653	C.E. perforated pellet	2 oz. pellet	0/0	Porter press	Explosion		Foreign particle inside press
377	TNT			Press	Explosion-Fire		Expl. dust and pulley slipping-friction initiation
757	Flake TNT	16 gr	0/0	Stokes pellet press	Explosion	Damage to immediate area	Foreign metal initiated (friction) during operation of press
10	Gunpowder	2 pellets + 40 lb (hopper)	0/2	Press	Explosion		Loose powder ignited by friction; pressure between extracting shoe and mold

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
943	M17 Prop Mix	90 available (top of block initiated)	0/0	11-3/4 vertical blocking press	Explosion		Ignition of solvent-vapor by adiabatic compression
1127	Black powder	(6) 30 mm pellets	0/1 burn	Press	Explosion-Burn		Unknown
975	Black powder	100 + 1500 charge house	0/0	Pellet press	Explosion-Fire	Immediate area	Unknown (possibly friction)
965	Boron - P. nitrate igniter comp	24 pellets (2 lb) + 7 lb on table	0/0	Stokes rotary press	Explosion-Fire	Immediate area	Friction between die and upper punch
699	Black powder			Block press	Explosion		Rapid compression of solvent vapors caused heat build-up to initiate explosive
612	Double base Nitrocotton-51.4% Nitroglycerine 42.9% (solventless)	70	0/0	15" R.D. cordite press	Explosion-Fire	Limited to building 47/-	Compression of powder under flappers when pressed against room face
1048	Butadiene-M-Ammonium Nitrate	75	0/0	1070 ton extrusion press	Fire	Immediate area of press	Autoignition-adiabatic compression due to breakdown of limit switch controlling initial ram
1082	ABL 2056-D propellant		0/0	Watson-Stillman finishing press	Explosion	Immediate bay area	Ignition of solvent vapor vapors-adiabatic compression
833	ARP double base casting powder	"2 blocks"	1/0	Finishing press	Explosion	Immediate bay area	Adiabatic compression of solvent vapor (ether alcohol) due to blockage of vent
801	M-7			15" R.D. wood press	Explosion-Fire	625/	
1226	M-30 propellant			Farquhar 12"	Explosion-Fire	Immediate bay area	Adiabatic compression of entrapped vapor

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING PRESSING (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSES
1212	Double-base casting powder	140/180	0/0	Finishing press	Explosion-Fire	Immediate area within building	At die and bottom of press basket surface) lateral motion-friction
1387	RDX pellets	1	1/3	Press	Explosion		1) Adiabatic compression of air trapped in wax or interface of wax and propellant-hot spot 2) Contaminated area-interface (propellant leakage) causing heat of friction initiation
1193	N4 (solvent-less) double base composition	100 (press) 707 (stored)		Farquhar 15" horizontal press	Explosion	Immediate building	Friction initiation - due to foreign metal inclusion between ram and basket
1377	C-3 prop	60	0/0	Blocking press	Fire	Damage in immediate building	
64	SF62(.4x.4 pellets)	165 gr	0/1 (burn)	(3) Triple punch Norssam presses	Explosion	Immediate area near punch	Perforating needle failur failure introduced as foreign article
714	Powder		2/5 (burn)	Horizontal finishing press	Flash Fire		During extrusion process
1013	AlClo	353 gr	0/1 (burn)	400 ton compaction press	Explosion-Fire	Minor damage	Misalignment of die mandrel & retaining mandrel causing interference (metal-metal)
862	Casting powder O.I.O		0/0	Pawfoot press	Explosion (minor)	Superficial damage	Adiabatic compression - solvent vapor
1040	T36 prop	50 (rework)		Blocking press	Explosion		1) Heat by friction caused by interaction of ram head and cylinder wall and included powder buildup at interface (normal) 2) Friction at cylinder interface caused by mechanical failure at lower end of ram
1174	X-8		1/3	Evenspeed roll	Flash Fire		Unknown

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
38	Detonators-Lead Styphnate	45-15 grain each	1/2	Transferring detonator to tray	Explosion-Fire	Immediate Area	1) Impact 2) ESD (unlikely 75% humidity)
58	TNT (Bomb)	150	0/2	Loading into wooden trays	Explosion		Impact
63	5 grain A/2 Detonators	15-5 grain each	0/1	Transfer Operation	Explosion		Impact
66	Igniters-S.R. 371 C	3-232 grains each	0/4	Filling Operation	Reaction		Friction
358	Grenades-#36		1/0	Inspection-Loading	Explosion	Immediate	Impact (Human Error)
359	15 in. Shells Mix	500	5/0	Screw Filling Hopper	Explosion		Friction (foreign object in hopper)
362	Amatol (50/50)	1/2	0/4	Transfer Operation after filling 75 mm H.E. gas shell	Explosion		1) Friction 2) ESD
364	Amatol (80/20)	75	3/1	Screw-Filling Operation for Extrusion	Explosion	300/-	Friction (foreign matter or solidified Amatol in hopper screw feed)
369	Amatol (60/40) 100°C		1/3	Filling Operation	Explosion		Impact (impact of brass tool on solidified composition)
387	Amatol (50/50)		2/4	Loading Shell Operation	Explosion		1) Friction (metal-to-metal contact with hammer) 2) Impact
432	Lead Azide - Comp. A		0/1	Transfer of "over-filled" detonator by operator	Explosion		1) ESD 2) Friction
439	Dynamite	2000	4/0	Loading Machine	Explosion	-/1 mile	ESD (ungrounded machine, low humidity)
561	Lead Azide-CE Detonators		0/1	Filling Operation (supply bowl detonated)	Explosion		ESD (brass filling ladle came into contact with brass scoop
600	Lead Azide - CE increment for 8.6 grain A.Z.Y. detonators	200 grains total	0/0	Filling Operation	Explosion		Friction (moving parts)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
608	5 grain A-Z detonators	20-5 grain each	0/2	Filling Machine (delivery chute)	Explosion		Friction (tapping-attempt at disruption of blockage)
621	M17 Detonater		0/1	Filling Operation	Explosion		Friction (dust ignition on work table/sleeve interface) Impact (insertion of aluminum foil into detonator)
636	Lead Azide and C.E. 6 grain detonators		0/0	Filling Operation Hopper Charge Explosion	Explosion		Friction (between guide plate and charge plate)
639	Dynamite	10,000	0/0	Pack-house	Fire		ESD (powder in paraffin dip pot ignited)
641	Lead Azide 6 grain detonators		0/0	Loading Operation	Explosion		?
654	Flash Bombs	25		Weigh-Fill Operation	Fire		Friction
659	?	1100 grains	0/1	Filling Operation	Explosion		Friction (attempt at cleaning blockage with pin on charge plate)
663	Lead Azide	5	2/0	Filling Operation	Explosion		1) Friction, 2) Impact, 3) ESD
1204	Illuminent Comp.		1/6	Charge Removal from Blender	Explosion-Fire		Unknown - No specification
1371(T)	M2- Relay/ Delay Elements		0/5	Syntron Feeder	Explosion		Unknown - No specification
1375(T)	Zirconium, Lead, Ethyl Acetate	2½	1/0	Filling-Hopper Operation	Explosion		Unknown - No specification
1389(T)	NOL 130 Primer Mix		0/0	Dumping into Blender	Explosion		Unknown - No specification
1590	Lead Azide, 3 flasks	20mg/flask	0/1	Transfer Operation	Explosion		Impact (dropped tray)
1598	Primer		0/0	Syntron Hopper Bowl-during Dumping Phase	Explosion		Unknown - No specification

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1599	NOL Primer Mix		0/1	Transfer Operation	Explosion		ESD ?
1612	Nitroglycerine and Gun Cotton Gelatinizing	250 kg	5/0	Loading Drais-Mixer (manual)	Explosion		Unknown - No specification
1619	Nitroglycerine-Azotic Cotton			Loading Gendu Mixer	Explosion-Fire	300/600	1) Friction (mechanical failure) 2) ESD (low humidity)
1640	Nitrocellulose Powder		40/11	Loading Room	Fire-Explosion		Unknown - No specification
1641	Mark 95 Detonators		0/1	Transfer Operation	Explosion		Unknown - No specification
1650	HMX	100 g	0/1	Filling Operation into Nitrator	Explosion		Unknown - No specification
1664	AIA Pyrotechnic	150 g	0/1	Transfer Operation	Explosion		ESD (improper ground)
1702	Detonators M223 Grenade Mix		0/1	Automatic Transfer Operation	Explosion		Unknown
1703	PA-100 Primer Mix	120 g	1/0	Transfer Operation	Explosion		Unknown-No Specification
1403 (T)	NOL Primer Mix, Lead Styphnate Dextronated Lead Azide, Tetrazene, Barium Nitrate, Antimous Sulfide	1.75	0/1	Unloading/Handling after Blending Phase	Explosion		ESD?
57	Detonator facility	4-5	1/1	Transfer Operation	Explosion		ESD
84	Igniter, Tetryl		12/50	Loading Operation	Explosion		Faulty Fuse Assembly

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
88	Aluminum Flare Composition (reworking material)			Transfer Operation	Explosion		Heat (hot spot ignition from IC engine nearby)
119	White Phosphoric Igniter		0/2	Transfer/Handling Operation	Explosion-Fire		Spontaneous Ignition (defective fuse)
120	Smokeless Powder	4000	1/0	Filling Operation on Feed Hopper	Fire		1) Impact - mechanical failure of hopper 2) Friction - between screen and hopper
132	Powder (Howitzer Shell)		3/2	Transport/Handling Process	Fire-Explosion	250/-	1) Friction 2) Static electricity 3) Foreign substance
	Firecracker Mix - (Potash Ground alum., Antimony)			Filling Operation	Fire-Explosion		Friction (contamination in between floor cracks)
178	Bombs		5/21	Packaging/Shipping	Explosion		Friction (between nose plug and bomb casing during handling)
261	Signal Lights-Dry Pellets		11/14	Transfer Operation	Explosion		Unknown - No Specification
262	Primer (fulminate)	595	3/6	Packing/Shipping	Explosion		1) Impact 2) Friction
312	M52 Incendiary Bombs- Black Powder-Primers	No. = 3000	0/1	Assembly/Loading Operation	Fire		1) Impact 2) Friction (human error)
314	Rocket Signal Star Pellets		1/0	Filling Operation	Fire		Impact .(fall)
323	Primer Expl.	35 (Cal 30/50)	0/15	Filling/Loading Operation	Explosion		Impact (carelessness)
334	Black Powder		0/1	Supply Filling Operation for Pelleting Machine	Explosion		Friction

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AGENT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
451	Pyrotechnic Green Star Mixture		0/2	Mold Transfer Operation for Press	Explosion		Friction
596	Nitroglycerine - Dynamite	1200		Transfer/Loading Operation at Tally Mix House	Explosion	400-1850/500	Impact (mishap during delivery)
1347	NOL 130 Primer Mix	1.77	0/1	Post-Blending Process-Transfer Operation	Explosion		Unknown - No specification Guess - friction
722	8.6 grain AZY Detonator, Lead Azide, Comp. A		0/1	Pellet Extracting Machine	Explosion		Friction (surplus material)
737	Composition: Magnesium, Aluminum, Potassium Perchlorate			Discharging material into Receiving Buckets	Explosion-Fire		1) ESD 2) Heat (Magnesium water reaction) 3) Vibrator failure
746	A. Z. Detonator	7-5 grain detonators	0/1	Assembly/Loading	Explosion		1) Impact (from pit stick) 2) ESD
747	303 Cartridge Caps Mercury Fulminate, Potassium Chlorate, Antimony Sulfide, Sealed Powder, Sulfur		0/1	Refilling Hopper Supply	Explosion		Friction
756	30 cal. Primers		0/1	V&O Primer Insert Machine Filling/Pouring Primer into a cup	Explosion	15/10	ESD (non-conductive shoes)
758	Rocket Grain Mark 16 (Black Powder)		0/1	Extraction/Removal of Rocket Motor via Air Blowout Machine	Explosion		Friction (between faulty igniter and front closure device)
762	Rocket Grain Mark 16 (Black Powder)		0/0	Extraction of Igniter with Blowout Machine	Explosion		ESD
766	Lead Styphnate	3	1/0	Preparation for Filling	Explosion		1) ESD (non-conductive arch supports) 2) Impact

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
824	Photoflash Composition for 762 mm Rockets		0/0	Remote Filling/Loading Operation from Hopper	Explosion		1) Impact (foreign body) 2) Friction (from gate valve assembly or foreign particle)
859	Al. Detonators		0/2	Assembly/Insertion	Explosion		1) Friction 2) Impact (between cover plate and detonators)
861	A.S.A. Composition: Lead Azide, Lead Styphnate	16		Dumping/Unloading from Mixing Process	Explosion-Fire		1) Friction (mixing bag) 2) Impact
865	Wet lead trinitroresorcinate	4.4	1/0	Weighing/Handling at Drying Station	Explosion	164/82	1) Impact (dried out material state) 2) Friction
869	Electric Detonators			Assembly/Transfer Operation	Explosion		ESD (low humidity)
881	Experimental Propellant	850		Unloading/Dumping of Barrel Tumbler	Fire		Impact (spillage)
904	Gelatin	3000	6/1	Gelatin Pack House	Explosion		Unknown - No specification
921	Nike Hercules Motor (Propellant)		0/2	Transfer/Carry Operation	Fire	200/-	Severe Impact
950	Electric Delay Detonators		1/0	Detonator Manufacturing/ Handling		0/30	Unknown - No Specification
1011	Giant Gel, 40% Dope, Sulfur		0/0	Feed Hopper/Weigh Station	Flash Ignition		1) Impact 2) Friction (hard 6061 Al. and steel interface)
1030	Primer Mix NOL - 130	3/4 ounce		Loading/Filling with Jones Loading Machine	Explosion		Friction (manual; between scoop and recepticle)
1051	M1 Smoke Pots (match-head mix)		1/0	Post Blend Emptying Operation	Explosion		Unknown - No Specification
1075	Grenade - Pyrotechnics Agent (unclassified)		0/3	Transfer/Handling Operation for Seaming Machine	Fire-Explosion		1) Friction (between tray and cabinet) 2) Spontaneous Ignition 3) Friction (between pail and metal cabinet)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1134	Pyrotechnic Mix, Potassium Chlorate, Sulfur, Sodium Bicarbonate		1/0	Unloading Operation of Read 84-178 Vertical Mixer	Explosion		Impact
1163	WP Filled Grenade		1/4	Assembly/Insertion	Explosion		Unknown - No specification
1168	High Energy NIBEX Propellant (Zirconium)	150	0/3	Dumping into Hopper	Fire-Explosion		1) Impact 2) ESD - dust accumulation in hopper
1214	M406, 40 mm Round, Composition B, Composition A5	32 gr.	1/15	Assembly/Handling	Explosion	32/-	Defective fuse caused premature ignition
1296	M1 Multi-perforated Single Base Propellant		2/4	Post-Dumping/Removal of Empty Plug Buggies from Area	Fire-Explosion		1) ESD 2) Crushing; Impact
1302	Primer Electric Model 52, Lead Styphnate, Graphite Potassium Chloride, Barium Nitrate		0/5	Filling Process on Conveyor Belt	Explosion		Friction (metal-metal)
1325	MK43 Mod Rocket Grain: (35% NG, 46% NC) N-5 Rocket Paste	1870	1/3	Charging/Unloading Operation for Blender Barrel	Explosion-Fire		1) ESD 2) Friction (vibrator)
1547	C4			Hopper Dumping Operation	Ignition		Unknown - No specification
25	Nitroglycerine	7500		Loading/Storage Operation	Explosion		Impact
17	ROP Cordite			Incorporating House/ Packing	Explosion		Unknown - No specification
1273	Gilsonite, Sulfur Aluminum Fines		0/2	Charging/Loading Feed Hopper	Fire		Unknown
792	2¼" Olgen Seismograph		2/0	Gelatin Pack House	Explosion		Unknown - No specification

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1121	Gelatin Dynamite	400 kg.	7/0	Transfer Operation in Mix House	Explosion		Impact
1126	Explosive Blasting Cap		0/50	Manufacturing Process	Explosion		Unknown - No specification
1141	Gelatin	3000		Gelatin Pack House	Explosion-Fire	1000/2000	Unknown - No specification
386-4	Picric Acid			Handling/Transfer Operation	Fire		Friction - friction between metal container and wall interface
1340	ANFO AN Prills	50M 5M		Howe Richardson Bagging Machine	Fire		Unknown - fire at diesel fuel area
349	Fire Gun Powder	2800	5/2+	Dryhouse (handling)	Explosion	350/	ESD - explosive dust explosion
601	Lead Azide	10 grain detector	0/1	Unloading moulds from extraction unit	Explosion	5-10'/--	Invested mold was brought in contact with surplus; explosion on top of the extraction machine
786	Ammonium Dichromate	150	0/0	Aluminum drum collector	Fire		1) Spark impingement of particle against metal valve on receiving can (ungrounded) 2) Heat of friction - V belt 3) Air lock valve blade became overheated due to friction
755	Multi-perforated single base M10 cannon powder and graphite dust	3000 and additional 2000	2/3	Loading preblender hopper	Explosion-Fire	900/4500	1) Static discharge due to powder impingement

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
615	Composition A	--	0/0	Filling Unit	Explosion	--	Friction-metal-metal contact
882	Nitroglycerine, TNT, Nitrocotton, Dynamite, Dope	350/300/ 150/2700 /760	0/0	Dope Handling Unit	Fire-Explosion	400/1500	Unknown
569	Smokeless Powder	130,000	9/0	Filling Bin	Fire	--	1) Friction-metal-metal contact by opening slide gate on car 2) ESD
807	Black powder potassium nitrate	3500	2/0	Pack House	Explosion	100/-	--
1128	Powder dynamite	4620	2/4	Packing House	Explosion	900/-	Friction? container floor spark
1218	Lead Azide	15	1/13	Weighing Filling Operation	Explosion	Immediate Building	1) Impact initiation (dropping freon spray nozzle) 2) ESD 3) Friction initiation (Spatula and compound)
777	Photoflash Powder	16 and add 40		Loading Machine	Explosion	475/470	Impact or friction initiation
887	Hi-speed	1100	2/2	Cartridging Machine	Explosion	600/600	Unknown
1339	Nitroglycerine	7000	1/13	Loading Operation	Explosion	1200/3200	Unknown
1033	Dry nitrostarch	100	1/0	Unloading dryer	Explosion	75/0	Unknown
776	Photoflash Powder	25	0/3	Loading/filling machine	Explosion-Fire	Immediate Area	Static discharge
994	Petrogel #1		0/0	Filling/packing	Fire Flash	--	Sliding catch box over contaminated propellant
1272	M9 Propellant	--	2/32	Loading Machine	Fire-Explosion	--	Mechanical malfunction
1448	M9 Propellant		0/3	Loading perry accofil machine	Flash Fire	NA	Friction of exposed sensitive explosive

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING FILLING (concl)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
3	Detonators	No. 13 detonator plug 190 grains	1/0	Breaking down detonators (dismantling)	Explosion	10/-	Striking detonator with a sharp tool and hammer
952	Ammonium perchlorate developmental	--	3/1	Removing oxidizer slurry from tank	Explosion	--	Probing of packed sludge with a rod (friction/impact)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
390	Acetone Solvent and Paste		0/0	Melvin Incorporators	Fire		Friction (drive gear, clutch slippage and dust contamination)
499	Smokeless Powder (40 mm cannon)	154,450	3/13	Blending-Hopper Dumping Operation	Fire	1800/-	1) Impact 2) Friction } spark from dropped article
531	Nitro-glycerine, low Nitro, Amonium nitrate dynamite	75 1250	2/0	Mixing Operation-Talley Machine	Explosion	600-1100/ 1300	Unknown-No Specification
580	Primer Mix Lead sulphocyanate, Antimony sulfide, PETN	12	0/0	Frankford Arsenal Blending Machine	Explosion		Friction (a) due to overmixing of dried out composition (b) foreign article
592	Nitroglycerine			Mix House, Transfer Buggy Explosive	Explosion		Unknown - No Specification
627	Primer Mix # 90, lead sulphocyanite, antimony sulfide, PETN, Potassium Chlorate	12	0/0	Blending Operation	Explosion		Friction
674	Smokeless Powder		2/0	Mixing Operation	Fire-Explosion	100/-	Unknown-No Specification
684	Mixed Dope		12/4	Mixing/Screening	Fire-Explosion	625-1100/ 800	Unknown-No Specification
694	Detonite	500	0/0	Mixing Operation	Explosion	150-300/ 4000	Unknown-No Specification (guess friction)
1352 (T)	Barium Chromate, Boron VAAR (90%, 9%)		0/0	Simpson Mixer	Fire		Unknown-No Specification
1365 (T)	NOL 130 Primer Mix	2½	0/1	Blending Operation	Explosion		Unknown-No Specification (guess friction)
1380 (T)	NOL 130 Primer Mix		0/0	Remote Blending Operation	Explosion		Unknown-No Specification

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1392 (T)	M63 Igniter Mix	5	0/0	Hobart Mixer	Explosion		Unknown-No Specification
1393 (T)	Trip Flare Mix-M49A1 Barium Chromate, Vinyl Acetate, Alcohol Resin Binder	25		Preparation/ Mixing	Fire		Friction
1403 (T)	NOL 130 Primer Mix, Lead Styphnate, Dextronated Lead Azide, Tetrazene, Barium Nitrate, Antimony Sulfide	1.75	0/1	Blending-Charge Removal	Explosion		ESD
1470	Whistle Composition: Oxides of Carbon, Sodium and Potassium		1/0	Mixing/Blending	Explosion		Unknown-No specification (guess ESD)
1571	Dynamite	3000	6/3	Mixing Process	Explosion		Unknown-No specification
1593	Monopropellant NOS366		0/0	Formulation/ Mixing	Explosion		Unknown-No specification
1595	Tracer Mix	50	0/0	Mix Operation	Explosion		Unknown-No specification
1615	Wood Powder Ammonium Nitrate		0/2	Mixing Process	Fire		Unknown-No specification
1629	Magnesium Teflon			Blending Operation	Deflagration Fire		Thermal (chemical instability - water and megnesium)
1637	PETN	10-20	1/0	Spin/Mix Operation	Explosion-Fire		Unknown-No specification
4	Propellant		8/25	Mixing Operation	Fire-Explosion		1) Friction (mechanical failure of mix paddle) 2) Impact (failure of paddle on foreign object)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
24	Black powder	1700 (Total) 50-100 (Barrel)	2/0	Sweetie Barrel Pre-Blending Operation	Fire		1) Impact 2) Friction 3) ESD
45	Powder	137/300		Powder Mixing Department	Explosion		Friction
205	Aluminum Composition Flare Mix (Grain Alcohol, Sodium Acetate Barium Nitrate, Castor Oil)	100	3/2	Blending Operation	Fire-Explosion		1) ESD (Dust ignition) 2) Friction (Foreign material) 3) Spark-electrical (motor wiring short)
238	Smokeless Powder -Cannon Powder	100,000		Blender Operation	Fire		Unknown-No Specification
291	Black Powder Reject and Additives		0/0	Mixing Operation	Explosion	1 mile/	1) Friction 2) Solvent Evaporation Overheat?
300	Barium Peroxide, Powder Magnesium Powder Aluminum	3400g. 400g. 200g.	1/1	Mixing Operation	Explosion-Fire		ESD (operation not grounded) and dust contamination
308	Strontium Nitrate, Magnesium Bee Wax, Shellac	14.25	1/0	Sigma Blade Mixing Machine	Explosion	225/-	1) Bearing Friction 2) Foreign Material - Friction
767	Blasting Powder	200	0/0	Powder Mixing House	Explosion	-/600	Unknown-No specification
809	HMX Base	122	0/0	Baker Perkins Mixer		300/600	Unknown-No specification
837	Dynamite Nitroglycerine	1600 460	2/3	Dynamite Tally Mix Operation	Explosion	600/-	Unknown-No specification
871	Rocket Propellant and Solvent		0/0	Baker Perkins Mixer/Cleaning Operation	Fire		Friction (ignition of solvent vapors during scraping)
894	Rocket Propellant (solid) XM30	2000	0/0	Baker Perkins Sigma Blade Mixer	Explosion		Friction (blade-container and dust ignition from spark)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
902	Pyrotechnic Mixture: Sodium Nitrate, Magnesium Laminac Binder, Acetone, Air Vapors	3½	0/0	Mix Operation-Simpson Mixer	Explosion		1) Friction (foreign material within container 2) Hot Spot Ignition (hot motor and dust ignition)
905	Gelatin	4000	3/2	Mix House	Explosion	800/1-1½ miles	Unknown-No specification
951	Rocket Propellant Composite NG, Polyester, Alum Powder, Ammonium Perchlorate	10		Mixing Operation Baker Perkins Sigma Blade	Explosion		1) Friction (between blade and food or foreign object) 2) Thermochemical Exothermic reaction-Instability
977	Rocket Propellant Composition (Tvpe HDDR-A) Alum Powder, HMX Slurry, Ammonium Perchlorate, Acetone, Alcohol		0/0	Readco Single Arm Double Blade Mixer	Fire		Friction (blade and bowl or foreign object)
992	Pyrotechnic Mixture, 7-27% Laminac, 23.9% Boron, 68.7% Potassium Nitrate, 500 grains of Trichlorate Ethylene		0/1	Mix Operation	Fire		1) Friction (metal-metal) 2) Friction (between solid contaminant on blade and metal bowl)
1001	Propellant Slurry Type MR382	350	0/1	Vertical Mixer with Turbine Blades	Explosion		1) Impact (foreign object) 2) Friction 3) Friction (seal-shaft contamination) 4) Cavitation
1003	Polysulphide Perchlorate Solid Rocket Propellant	2882	0/11	Baker Perkins Sigma Blade Mixer	Explosion		1) Frictional Heat (fuel oxidizer in packing gland range) 2) Friction (blade-wall) 3) Pinching(metal separation, shift-packing interface, cracks, crevices)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX.DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1021	Experimental Igniter Mixture		0/0	Blending-Twin Shell V Blender	Deflagration		1) Friction 2) Impact
1024	Tracer Composition XMI2E2	50	0/0	Mixing Operation			1) Friction 2) Impact
1035	Composite Propellant Fuel and powdered alum paste oxidizer - ammonium perchlorate			Mixing Process	Fire		1) Friction Overheat 2) Friction between discharge spout and line bin 3) Friction from bin vibrator
1064	Propellant, ammonium perchlorate, alum composite			Mixing Operation Read Horizontal Mixer	Explosion		1) Impact 2) Friction
1067	Tracer Mix XM13		0/0	Simpson Mixer	Explosion		1) Friction 2) Impact
1072	Unspecified Explosive	500-1000	3/8	Mix House	Explosion		Unknown-No Specification
1096	Lead Azide, Calcium Stearate-Jelly Bags			Mixing Cycle	Explosion		Unknown-No Specification
1114	Charbrite Mixture			Collete Mixing Equipment	Explosion		Unknown-No Specification
1154	Phosphorous Pentachloride and Fluorinated Alcohol		0/1	Stirring/Mixing	Violent Reaction		Thermal-Runaway chemical reaction
1167	R&D Propellant	10	2/0	Horizontal Mixer-Sigma Blades	Explosion		Thermal-Runaway chemical reaction
1200	Propellant Mix (Minuteman)		0/0	Batch Mixer	Fire-Explosion		Friction-blade-lining-foreign object
1204	Illuminant Composition		1/6	Blender-Charge Removal	Explosion-Fire		Unknown-No Specification
1237	P.D. Delay Composition		0/0	Simpson Mixer	Fire		Friction-internal friction of composition
1257	Hi-energy Propellant Hydrazine Di-Perchlorate	57	0/0	Baker Perkins Vertical Mixer	Explosion		1) Impact 2) Friction

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (cont)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1270	Gelatin Dynamite and Nitro-glycerine			Mix Operation	Explosion	350-800/1200	Unknown-No specification
1286	N5 Propellant Paste	880	0/2	Blender Dust Collector Roto-Clone Apparatus	Explosion		1) Friction 2) Pinching
1322	Slurry Mix		0/1	Hobart Mixer			Friction (metal contact between liner and paddle)
1206	Double Base Propellant (NC, amm, Perchlorate and Aluminum)	720	0/0	Mixer	Fire		Foreign objects (metal) frictional heating of blade-object-lining interface
1261	TP-H1085 Propellant	4400	3/2 (fire)	Baker-Perkins mixer 300 gal (scrape down)	Fire		Ignition of ammonium perchlorate/sublimed recrystallized ferrocene by heat of friction. Action: steel spatula/liner during scrape down
1289	Single base multiperforated powder	5000		Mixer (discharge into buggy)	Explosion		Ignition of dust granules by ESD
811	Propellant composite	500	2/0	Mixer	Explosion-Fire	(900/2000)	Foreign article-scraping tool inside mixer caused frictional heat initiation between blade and liner
964	Polysulfide perchlorate			Extruder	Explosion		Friction: 1) foreign object 2) blade and linear contact 3) solid buildup
657	Propellant Carbon black Nitrocellulose Ammonium perchlorate		0/0	Mixer	Explosion	400/-	Too low a content of solvent in mixture (dry friction)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MIXING (concl)

ASESB NO.	AGENT	AMOUNT (LBS)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSE
1473	Casting (20% scrap powder)	620	0/0	Talley mixer	Fire	-/-	Friction between blade and lining
920	Dynamite-Nitroglycerine	1000 700	2/5 (frag)	Talley machine	Explosion	600 ft/3 mi	Unknown
1309	C-3 casting powder		0/0	Mixer	Fire-Explosion	Bldg only	Foreign particle/failure or blade; friction/impact
896	Composite propellant	98 lbs	0/2 (flash burn)	20 gal Baker Perkins mixer	Explosion	-/-	Foreign article between blades and liner caused frictional heating/impact
878	Polysulfide base TRX 110C propellant		-/-	200 gal Baker Perkins mixer	Explosion-Fire	150 ft/-	1) Blade clearance .088/.109 in - friction 2) Static spark (gas leakage observed-ammonia perchlorate and fuel)
729	Composite (nitroguanidine, K_2SO_4)	200 3.9	0/2 (fire)	Mixer charging	Fire		Sigmablade-frictional heating
1310	NACO propellant single base	"8 blocks"	2/1 (burn)	Mixer	Fire		1) Foreign material-friction 2) Dehydration of mixture increasing sensitivity for impact 3) Metal-to-metal blade lining contact caused by initial deflection of resistive force with NACO blocks
472	M7 propellant	450 lb	1/1 (blast) victim thrown 120 yards	Mixer	Explosion	-/-	Friction-blade-lining pressing of dry potassium perchlorate pre-blend (.025 in. clearance)
1080	Polybutudiene amm. perchlorate and MAPO (solid propellant)	280	0/0	Mixer	Fire		Spontaneous autoignition of MAPO - no blades in mixer

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MAINTENANCE

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
355a	Fuel-Vapor (Alcohol)	5 gal. can	0/3	Alcohol Tank	Explosion		
355b	Tetryl Lead			Cleaning Operation on Lead Crystallizer	Fire-Explosion		Direct Flame on Trapped Explosive
355c	Tetryl			Discarding Lead Pipe	Explosion		Impact - Lead Pipe and Tetryl
355d	Tetryl			Maintenance Operation on Valve Seat	Explosion		Direct Flame Exposure
355h	Tetryl		0/3	Maintenance/ Soldering on Contaminated Tetryl Car	Explosion		Thermal - Heat Application
355e	Tetryl			Maintenance/ Replacement of Lead Cover	Explosion		Unknown
355g	Mixture- M3 Flare			Welding	Explosion		Hot Spot - Contaminated metal mold
363	Boosters - MK III, IIIA (TNT and Tetryl)		0/0	Soldering	Explosion		Thermal - overheated and dust available
589	Lead Azide mixture		1/1	Spray Painting Operation of 120 MM Filled	Explosion		1) ESD 2) Friction (foreign particle)
1370 (T) and 1328	NOL 130 Primer Mix		0/1	Maintenance Operation on Jones Loading Machine	Explosion		Friction
1383(T)	Lead Azide			Maintenance Operation in Storage Area	Explosion		1) Impact 2) ESD
1414(T)	TNT dust		0/0	Cleaning/ Maintenance	Explosion		1) Friction 2) Mechanical Failure of Blower - Impact
1420(T)	Igniter Composition Mix		1/2	Maintenance Operation on Mixer	Explosion		Friction - contamination

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MAINTENANCE (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
213	Black Powder			Disposed Operation	Explosion		Unknown-No specification
244	Gun Powder		4/7	Salvage	Explosion		Unknown-No specification
266	Not Specified		0/5	Maintenance Operation for Press	Explosion		Unknown-No specification
315	Black Powder	<5000	5/2	Press Maintenance Operation	Fire-Explosion		Friction (metal-metal)
772	Experimental Explosive for 105 mm round		1/1	Maintenance/Cleaning	Explosion		1) Friction 2) Impact
871	Rocket Propellant and Solvent		0/0	Cleaning Operation/ for mixer	Fire		Friction-foreign material scraping and vapor ignition
931	Hydrogen Peroxide			Drainage/Disposal	Explosion		Flammable Fuel Ignition
973	Igniter Composition	1/4	0/1	Handling/Cleaning of Pelleting Press (Kur Lehnar)	Flash Ignition		1) Friction-between shoe and table 2) Pinching (compressing)
1025	Blasting Agent(fuel oil, ammonium nitrate)		0/26	Acetylene Torch Cut on Chute	Fire-Explosion	3 mile/5 mile	Open Flame
1062	M49 and M28B2 Artillery Primer		1/0	Maintenance Operation for Jammed Chute Component on Disposal Furnace	Explosion		1) Thermal 2) Impact (by operator)
1103	Aluminum Powder, Magnesium Perchlorate		0/2	Cleaning/Vacuuming	Deflagration	50/-	Friction and Dust Ignition
1112	Explosive Mixture Trialene (70% TNT 15% Hexogene, 15% Alum)			Maintenance	Explosion		Friction
1182	Chemical Filter Solution Water Methanol (50-50) and 5% Caustic		0/0	Decontamination/ Cleaning	Explosion-Fire		Fuel Air Vapor Ignition 1) Heat of Friction 2) ESD 3) Heat of Reaction 4) Friction-Sump Drain Actuation

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MAINTENANCE (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1299	Bomb Fuses		1/0	Inspection/Boat Disposal Cleaning/ Maintenance	Explosion		Unknown-No specification
386-5	Picric Acid			Cleaning Operation	Fire		1) Impact 2) Friction
386-10	Picric Acid Dust			Maintenance	Fire		1) Impact 2) Friction
386-13	Picric Acid			Cleaning/Maintenance	Explosion-Fire		Friction from tools
386-23	Picric Acid			Maintenance/Disposal	Explosion		Direct Flame - contaminated lead melt down
386-28	Picric Acid			Maintenance/Melt down of metal in furnace	Explosion		Direct flame-scrap metal contaminated with picric acid
611	"Explosive"	3/4	1/5	Maintenance-conveyor system	Explosion	Immediate area	Cutting torch-localized heat on contaminated vacuum pipe
626	"Dry" Nitrocellulose		1/2	Repair and maintenance	Explosion		Cigarette/match ignition of contaminated underground pipe
410	Contaminated waste water		1/0	Maintenance	Fire-Explosion		Waste water residue contaminated in basin. Fire initiated by friction from metal friction subsequent explosion of pipe caused by heating due to fire
356	Residual dry Nitrocellulose	5-10	0/5	Cleaning	Explosion		Swab initiated Nitrocellulose within pipe by friction
1234	Composition A-5	17-25 lbs + 25 + 5		Cleaning-maintenance	Fire-Explosion		Caused by striking vacuum kettle against garbage can to provide ignition by 1) Impact 2) Friction 3) ESD

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MAINTENANCE (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1180	Double base triple base propellant		1/0	Maintenance-welding of bride block	Explosion		Welding of contaminated bride block sufficient to allow localized heat initiation
1227	Lead azide resudial crystals		1/0	Cleaning	Explosion		Impingement of contaminated residual sludge by hose stream caused foreign objects within to abrade LA crystals
789	Nitrocellulose colloid		1/4	Hardening still (cleaning scraping)	Flash Fire		1) Impact from brass scraper 2) Friction-employee standing on residue material 3) Decomposition of remains within still

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MACHINING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1490	Nitrocellulose slurry	contaminated pipe section	0/1	Hacksaw blade	Explosion	10/-	Friction due to metal-metal contact
1499	Black powder (block)	41	0/1	Bandsaw	Fire		Friction between metal and black powder
1205	Propellant grain		0/0	Saw	Fire		Friction
1108	Reinforced grain (Minuteman rocket motor)	10	0/0	Vertical radial saw (hydraulic)	Fire		Inherent friction in machining of reinforced grain
735	Rocket grain		0/0	Dowel rod machine	Explosion	Immediate bay area	Friction initiation during machining
1254	Sparrow MK 38 mod 0 solid grain prop	91	0/1	1/32 Drill into prop	Fire		Friction heat buildup
959	Composition prop experimental Emerson-Cummings Epoxy resin catalyst alum. powder, pot. perchlorate	(cast) 3/4	(cuts) 0/1	Machining lathe	Explosion		Decomposition of Unknown experimental chemical
686	Mark 16 solid prop		0/1	Rotary saw	Fire		Spark initiation and (friction) heat buildup
899	Benite powder	41 strands	0/2	Bandsaw	Fire		1) Ignition of vapors due to friction caused by: a. Excessive saw speed b. Insufficient coolant flow c. Adherence of powder to saw and revolving under wheel of saw 2) Static spark ignition of alcohol vapors
602A	JON extruded MK22 grains	65	0/0	Saw	Fire-Detonation		Friction originated; drip vacuum enhanced spread of fire

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING MACHINING (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
355f	TNT			Machining stirrers	Explosion		Friction
355h	Smokeless powder		0/0	Machining ram press	Explosion		Friction
692	ANM50A2		0/0	Thermate drilling machine	Explosion		Friction & primer detonator initiation (detonator not secured prior to drilling)
1359	Comp B 60/40	4.5	0/0	Drilling operation	Explosion		Frictional heat buildup between workpiece and tool
1494	H.E. explosive	6		Drilling operation	Explosion		Friction between drill blade and fuze wall threads
1690	PBX	75	3/0	Machining rough billet 20" Monarch tracer lathe	Explosion		1) Friction 2) Impact
334(2d)	Primers		0/0	Drilling operation	Fire		1) Friction 2) Sparks
1037	Ammonium Perchlocate solid propellant	92	0/0	Cutting operation	Fire-Explosion		Frictional heat
633	Rocket propellant powder	56(initial) 548(total)	1/0	Cutting machine	Explosion		1) Friction-steel blade on machine ignited nitrogylcerine fumes or powder dust 2) Impact knife on machine guide causing shock initiation of nitro condensate
655	Mercury fulminate		1/2	Rebowling operation	Explosion		Inadvertent impact
1038	TPH 8126 composite propellant	total 7	1/2	Bandsaw	Explosion-Fire	12 ft/-	Ignition of propellant fines in lower guide blocks of bandsaw friction

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING EXTRUSION

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
583	Experimental propellant			Pressing-extrusion combined chamber machine	Fire-Explosion		Unknown, no specification
1185	ASROC (Cruciform grain - rework)		0/0	Press-extrusion operation	Explosion-Fire	660/-	1) Powder contamination 2) Friction (powder-powder) 3) Heat of impact 4) Trapped air compression within press bucket
1385	M30-multi-perforated triple base propellant	30	0/0	Extrusion press	Explosion	Damage in press bay	
1376	Multibase casting powder	35/80	0/0	Extrusion press	Fire		
835	Double base solventless rocket propellant Navy X-8		0/0	Extrusion press	Explosion		
773	N5		0/0	Extrusion press	Fire-Explosion	Bay area	Heat generated by fire near press
913	Ammonium perchlorate			Lombard horizontal extruder	Explosion	2 cells completely demolished	1) Friction of moving parts 2) Adiabatic compression of trapped air 3) Heat rise during normal operation 4) Oxidizer entrapped between moving parts
937	N-5 formula (solventless double base slurry)		0/0	Expeller/extruder	Explosion-Fire	860 ft/--	1) Friction generating heat hear torpedo head 2) Foreign material causing friction, pinching or impact

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING EXTRUSION (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1419	Triple base propellant	10	0/0	Extrusion press	Explosion	Damage to press, building	Foreign metal inclusion
976	Double base solventless	50	0/0	Watson-Stillman 15" horizontal extrusion press	Explosion-Fire	80/-	Friction; failure of Teflon ring seal; metal to metal contact; ram & press basket
690	M-10		0/2	Extrusion press	Explosion	Immediate area	1) Adiabatic compression 2) Rapid extrusion-localized overheating

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING SCREENING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE	PROBABLE CAUSES
671	Dope		0/1	Dope Mixer Screen	Ignition		Unknown - No Specification
1674	Lead Azide	1	0/0	Screening Operation	Explosion		1) Friction 2) Impact 3) ESD
92	Black Powder	6000		Screening/ Packing	Explosion-Fire		1) Friction (metal-metal) 2) Impact 3) ESD (not likely)
120	Smokeless Powder	4000	1/0	Screening House/Filling Hopper	Fire-Low Order Detonation		1) Friction (screen-hopper)
164	Black Powder	5000	2/5	Screening Operation	Explosion		1) Friction } Mechanical Failure 2) Impact } 3) Spark Ignition
1115	Lead Azide	140 g.		Sifting-Sieve Operation	Explosion		Unknown - No Specification
1603	Lead 2:4 Dinitro Resorcinate	1.2	0/0	Sieving	Explosion		Unknown - No Specification
1659	Lead Azide	1	0/0	Screening Operation	Explosion		Impact
684	Mixed Dope	3000	12/4	Screening/Mix Operation	Fire-Explosion		Unknown-No Specification
721	Mercury fulminate	9 oz.	0/1	Sieving	Explosion		Impact/friction initiated striking of funnel with brush handle
785	Lead styphnate	1-1/2 lbs.	0/0	Jelly bag screener	Explosion	50/	1) Impingement-during pouring of L.S. over screener 2) ESD

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING SCREENING (Concluded)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE	PROBABLE CAUSES
744	None-dynamite dope ingredients	--	0/0	Screener	Fire		Friction caused by foreign material in screen
751	None-dynamite dope ingredients	--	0/0	Screener	Fire		Electrical wiring
581	T9 powder pot. nitrate, ammonium picrate, aceton, ethylcellulose, zinc stearate, tri-calcium phosphate	1700 lbs. total in area	2/0	Blender/ screener unit and filling drums	Explosion		1) Frictional-metal-metal contact 2) Static discharge-all during operation
1184	Green smoke powder	--	--	Sifting	Explosion		Friction

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING STORAGE

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BRFAKAGE	PROBABLE CAUSES
1338	Ammonium Nitrate		0/8	Storage Facility	Explosion		Unknown - No Specification
1378(T)	Pyrotechnic material		0/0	Storage	Fire-Explosion		Unknown - Lightning; heavy rains
97	DuPont Nitro-glycerine	3000	2/8	DuPont Frame Shed	Explosion		Unknown - No specification
224	Ammonium Sulphate-Nitrate	4500 ton		Storage	Explosion		Stability unknown
207	Ammonium Nitrate			Storage	Explosion		Unknown
313	AN-M40 Signal flares and smoke pots			Storage	Fire		Unknown
386-3	Picric Acid			Storage magazine	Fire		Friction
386-11	Picric Acid			Magazine	Fire		Friction
945	Nitro-glycerine	3000	0/0	Storehouse	Explosion	1000/plant area	Initiation by range fire
1079	Nitro-glycerine	7540	1/1	Storage Tanks	Explosion	1000/1 mile	Unknown (friction possibility) deceased entered area with pail
528	Gun powder	36 tons	15/25	Storage	Fire-Explosion	1/4 mile 1-3/4 mile	Fire initiated
597	Powder	--	--	Storage	Explosion	--	Cigarette initiated
661	Nitrates a) Soda b) Ammonia	--	12/-	Storage	Fire-Explosion	Crater 22 ft Depth 6 ft	Unknown

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DRYING

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
280	Lead Azide-Tetryl for 6 gr detonators	12	1/0	Drying Operation	Explosion	20/-	ESD?
384	Picric Acid	1450(P)	0/22	Drying House	Fire-Explosion	750/2-5 miles	1) Friction (man's clogs walking through room) 2) Impact (... of picrate of iron by man's shoes) 3) Overheated (steam pipe)
385(1)	Ammonium Nitrate (AN)			Crystallizing Pan Shed-Drying Process	Fire		Heat (contaminated bagging placed on steam pipe)
385(2)	AN			Evaporating Plant	Ignition		Heat (thermal ignition of contaminated asbestos covering steam pipe)
385(4)	AN			Drying Process	Reaction		Excess heat-steam pipe cover contaminated with AN
385(5)	AN			Drying Process	Reaction		Excess heat application-hot bricks on AN thin layer
385(6)	AN			Drying	Ignition		Heat (contamination)
385(7)	AN			Drying Operation	Explosion		Heat (steam pipe and contamination)
1346	Nitrogylcerine	300	0/0	Drying Process	Explosion		Heat (high temperature over extended period, decomposition of nitrogylcerine)
1468	Igniter Composition for M49A1 flare	2000	0/0	Drying/Storage	Fire-Explosion		Unknown-no specification
1560	Solventless sheet propellant		0/0	Preheating Operation	Explosion		Unknown-no specification
1570	Primer Ignition Assy M63; M59			Drying	Explosion		Unknown-no specification
1604	Shotgun Powder	250	0/1	Drying Operation	Fire		Impact (on layer of powder)
1613	118 Electric Detonators			Drying	Explosion		Overheat due to faulty thermostat

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DRYING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1647	Red Water Facility-Thick Liquor		0/0	Drying/Heating	Explosion		Thermal (entrapped explosive material overheated)
51	DuPont Shotgun Powder	2080	2/0	Drier Operation	Fire		Friction
163	Black poweder	17,000	5/9	Dry House	Explosion		Unknown
218	DNT-TNT	25,000	36/2 (34 missing)	Drying Process	Explosion	2640/-	Heat (overheating)
270	Magnesium			Drying Operation	Fire		Heat (excess heat applied)
325	Ammonium Nitrate (1% H_2O)	4800	4/17	Evaporator Pan/ Drying Process	Explosion		Thermal (ignition from overheated lub oil in air agitator die)
1482	Propellant M26	7	0/0	Hot Pack Oven/ Drying Operation	Fire		Thermal (thermostat malfunction causing overheat)
728	M80 Firecracker Composition; Potassium Perchlorate; Alum flakes, Sulphur Antimony Sulphide		11/50	Drying Oven	Explosion-Fire	-/1600	No specification; guess-overheating
893	6 Nike and 10 Honest John Motors (propellant)		0/0	Curing/Drying Building	Fire		Electrical (lightning)
944	Dynamite; Nitrocotton, Gelatin		0/0	Dry House	Fire-Explosion	500/-	Open flames (from range fire)
1015	Ammonium Nitrate (oil sensitized)			Oven Operation	Fire		Thermal (thermostat failed)
1029	XM-30 Sustainer Motors (4)	9200	0/11	Curing Oven	Explosion		1) Thermal (leaking propellant into hot electric heating coils) 2) Friction/impact (from mechanical failure of clamps, therefore dropping the motors)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DRYING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1034	Explosive Comp Slurry: (Bismuth Trioxide, Magnesium, 1½% Binder Base-Methyl Ethyl Ketone (MEK)			Curing Oven	Explosion		Thermal: 1) Exothermic reaction of fuel 2) Hot spot formation 3) Organic peroxide from breakdown of MEK could have contributed in heat generation
1311	Arcite Terrier Sustainer grain		0/0	Curing Operation	Explosion-Fire		Thermal: contamination of mold with iron rust
386-7	Picric Acid			Drying Facility	Fire		Impact between bogie and iron pipe
386-8	Picric Acid			Picric Acid Drying Stove	Fire		Friction-spark ignition due to metal surface abrasion
386-9	Picric Acid			Drying Room	Fire		Friction between steam pipe and the support
386-12	Picric Acid			Stove Bed	Fire		Friction-metal to metal
386-18a	Picric Acid			Drying Stove	Fire		Thermal-hot spot on steam pipe
386-18b	Picric Acid			Drying Stove	Fire		Thermal-hot spot on steam pipe
386-18c	Picric Acid			Drying Stove	Fire		Thermal-hot spot on steam pipe
386-18d	Picric Acid			Drying Stove	Fire		Thermal-hot spot on steam pipe
386-25	Picric Acid			Drying Room	Fire		Unknown
386-27	Picric Acid			Drying Shed	Fire-Explosion		Unknown
374	Cordite/ Acetone Alcohol	55,790	2/10	Recovery Stove/ Drying Process	Explosion-Fire		No specification
1033	Dry Nitro-starch	100	1/0	Unloading Dryer	Explosion	75/0	Unknown
1287	Ball Powder WC852	6000 (initial) 13,780	0/0	Dryer	Fire-L.O. Detonation	Building area	Excessive heat buildup

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DRYING (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1467	Black powder boron pot. nitrate tungsten delay mix	20 20 1000	0/0	Dryhouse and oven	Explosion		Unknown
910	Dry Nitro-starch	850	0/0	Dryer	Explosion	75/-	Overheated motor in fanhouse
750	Nitrocotton	700	0/0	Dryhouse	Explosion	100/-	Unknown
712	Nitrocottom	400	1/0	Dryhouse	Explosion	1200/200	Unknown
394	TNT	300 stove 1000 drying 150 hopper 5-6 tons stored	0/0	Vacuum Drying Stove	Explosion		1) Decomposition accelerated by pressing of ammonium nitrate due to contamination in drying stove
393a	Cordite RDB		0/0	Stove	Fire		Unknown
393b	Cordite RDB		1/0	Stove	Fire		Ignition of solvent vapors
393c	Cordite RDB		2/2	Stove	Fire		Ignition of inflammable vapor in the vapor piping
393d	Cordite MD		1/5	Recovery stove	Fire		Vapor ignition of acetone air mixtures which were to be recovered
393e	Cordite RDB		0/1	Stove	Fire		Ignition of vapors
376	Di-nitro-phenol-picric acid		7/69	Drying room	Fire-Explosion	15 yd center 12 ft deep 500 yd missile	Initiation-smoking
383	Cordite RDB	47,332	0/0	Recovery stove	Explosion		Vapor ignition
534	Fulminate and tetraethylic substance			Hot air stove	Explosion		Overheating
1123	Mercury fulminate	55	2/0	Dehydration	Explosion	Building area	1) Initial ignition of dry fulmate by friction (metal-metal) with subsequent ignition of alcohol-air mixture in collector)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING DRYING (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
821	Single base prop (shock gel process)		0/1	Rotating drum dryer	Explosion		1) Loose metal supports within dryer initiated pellets by friction 2) Impact
1045	Mercury fulminate	5	0/0	Drying Operation	Explosion	60/50	Unknown
1125	Lead Azide Lead trinitro resorsonate	27	1/0	Dry house	Explosion	chamber/building	Impact (?)
1129	Lead Azide Lead Styphnate	22	1/0	Drying Operation	Explosion-Fire	-/60	Impact
1202	HP-2 Experimental prop	10 oz		Cure oven	Explosion	Immediate oven area	Thermal instability between HP-2 and other ingredients
1107	EM-27 prop			Curing facility	Explosion		a) High temperature b) Equipment failure c) Impact (slippage)
1056	FOC experimental motor mold			Curing house	Explosion-Fire	Immediate bay area	Impact and sympathetic reaction
349	Fire gunpowder	2800	5/2+	Dry house (handling)	Explosion	350/-	ESD-explosive dust explosion

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN REACTORS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1476	TNT	10,000	0/6 major 100 minor	Nitrator-separator	Fxplosion	3000/ 70 ft crater	Thermal/exothermic instability-inadequate mixing due to hose obstruction with agitator
1267	Nitro-glycerine	--	--	Nitrator	Explosion	--	Chemical decomposition of old spent acid within reactor-exothermic
502	TNT	--	0/0	Tri-nitrator	Fire	--	Thermal instability-caused by operator procedure
1117	Hexogene	--	0/0	Nitrator	Reaction chemical	--	Thermal instability-caused by mach failure
1191	TNT	--	0/3	Dinitrator	Reaction chemical violent	--	Exothermic reaction
1111	Nitro-glycerine	Small		Nitrator	Explosion	--	Temperature increase
982	Tetranitro-methane	--	--	Reactor	Explosion	Building destroyed	Poor agitation caused a runaway chemical reaction with excessive heat build-up; mechanical failure of agitator (friction/ impact)
1119	Nitro-glycerine	1100	2/-	Nitrator-	Explosion	~500 ft building destroyed	Block cock - friction oriented
380	Nitro-glycerine	5500	--	Nitrator-separator	Flame-explosion	--	1) Decomposition of impurities adhering to reactor shell 2) Decomposition of flacculent matter on surface of separated nitroglycerine

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN REACTORS (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
908	Nitro-glycerine		0/0	Dinitrator waste acid	Explosion	--	Contamination during cleaning exercise + thermal/decomposition
312	Nitro-glycerine	450x3 1350 lb	2/0	Reactor	Explosion	Building destroyed ∿500'	Unknown
603	Nitro-glycerine	--	0/1	Nitrator (Biazzi system)	Explosion	∿1000' plant destroyed	Decomposition of nitro-glycerine-runaway reaction due to excessive acid addition; heat generated and fast temperature rise
907	PETN Petrin acrylate (rocket propellant)	∿1 lb	1/3	Nitrator	Explosion	∿100 ft	Instability of impure PETN included with acid at ambient temperature and further decomposition of explosion with the addition or a water-acid base (accidental addition of water)

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN REACTORS (cont)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
368	TNT		0/0	TNT nitration process	Fire		1) Insufficient agitation-thermo-chemical runaway reaction 2) Chemical decom-position
373	DNT-TNT-acid mix		0/0	Nitrating reactor	Fire		1) Chemical ignition (acid-covered combustible) 2) Agitation failed - unstable temperature gradient
389	Nitroglycerine	6500	2/0	Nitrator	Explosion		1) Spontaneous decomposition 2) Friction - tool
392	Picric Acid		5/-	Nitration-waste water recovery	Explosion-fire		1) Chemical reaction (picric acid + iron oxide); sudden heat addition
462	Nitroglycerine	Initial 7000 lbs	3/0	Nitrator	Explosion	700 -3100/1200	Unknown, not specified-guess impact of foreign particle
498	Bi-oil + Acid (sulpheric nitric)	500-800		Trinitrator process	Explosion	200-1390 / 250-300	Thermochemical (extreme temperature rise caused by rapid addition of bi-oil and acid)
501	TNT		0/1	Trinitration process	Fire-explosion		Exothermic instability-runaway reaction insufficient cooling and rapid addition of bi-oil
678	TNT (oleum acid bi-oil)		0/0	Trinitrator Operation	Explosion		Extreme exothermic reaction due to insuf-ficient agitation and overheat
1466	TNT		0/2	Trinitration	Explosion-fire	300/-	Unknown - no specifi-cation
1566	Nitroglycerine		0/0	Batch NG nitrator	Explosion	-/3-5 miles	Unknown - no specifi-cation

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED IN REACTORS (concl)

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT.)	PROBABLE CAUSES
1573	Nitro-glycerine		4/0	Nitration facility	Explosion		Human error - no specification on stimulus
1172	NFPA-NFPOH (Classified)		0/0	Nitration reactor			Thermal: Unstable exothermic release due to lack of agitation and cooling
1183	Sulfuric Nitric acid plus tolulene bi-oil		1/3	Nitration process	Violent Reaction		Thermal: spontaneous heat addition; rapid volatilization and explosion
1236	DNT	6000		Tri-nitrator	Fire-Explosion		Thermal: high heat content with insufficient cooling (no compliance with SOP)
1621	Nitro-glycerine		0/0	Continuous nitrator process	Explosion		Unknown - no specification
1683	6-Amino-pencillanic acid, S-oxide, trimeric acetone peroxide			Small reactor	Explosion		1) ESD 2) Friction (technician touched filter cake with steel spatula For trimeric acetone peroxide sensitivity is: 11.5 mJ electric spark, impact-2 Kg at 10 cm, friction-.5 Kg weight
161	TNT			Nitrator	Explosion-Fire		1) Thermal (no agitation) 2) Chemical Decomposition of nitrobody
386-14	Picric Acid			Nitration	Fire		Thermochemical reaction with organic
386-15	Picric Acid			Nitrating house	Fire		Thermochemical reaction with organic

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING SOLVENT RECOVERY AND IN ACID CONCENTRATORS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE	PROBABLE CAUSES
150	Smokeless Powder	296-550	49/110	Solvent Recovery Line	Fire-Explosion	-3/4 mile	Nine (9) possibilities listed
234	Smokeless Powder		3/0	Solvent Recovery Process/Chute	Explosion		1) ESD 2) Friction-tumbling
954	Nitrobody/ Sulphuric Acid & Oil			Concentrator/ Recovery of Sulphuric acid	Flash Fire		1) Electrical short 2) Contamination
386-24	Picric Acid			Lead Pan Concentrator	Explosion		Unknown, acid overflow
386-26	Picric Acid			Acid Concentrator Plant	Explosion		Unknown, acid leak
386-29	Picric Acid			Acid Concentration House	Explosion		Unknown

SUMMARY OF SELECTED ACCIDENTS WHICH OCCURRED DURING WASHING OPERATIONS

ASESB NO.	AGENT	AMOUNT (LB)	FATALITIES/ INJURIES	COMPONENT OR OPERATION	OUTPUT-TYPE	MAX. DISTANCE MISSILE/GLASS BREAKAGE (FT)	PROBABLE CAUSE
375	TNT	4-1/2 tons (nearby)		Wash house/ scaling house	Flame-Explosion		Spontaneous ignition 1) TNT dust in fume pipe 2) bearings of fan-hot spot 3) heating pipe 4) decomposition of TNT by alkali
682	ANM50XA3 containing detonator and tetryl explosive incendiary bomb		1/16	Washing operation on bomb?	Explosion		Unknown, guess-defective fuze
?	NOS Indianhead Maryland 13, Sept. 1971 (nitroglycerine)	450	2/0	Prewash tank	Explosion		Unknown, no specification
382	Nitroglycerine Nitrocotton	3578 936	6/1	Washing	Explosion		Friction-wooden clip and rubber tube
1189	Lead Azide (alcohol and freon)	2	1/-	Filling flasks Washing-aspiration	Explosion		Friction due to bumping of flask and funnel

LIST OF SYMBOLS

A - surface Area (m^2)

a - significant dimension in thermal explosion model (cm)

C - specific Heat (cal/g°k)

C - capacitance for ESD calculations (farads)

E - activation energy (cal/mole)

e - impact energy per unit area (joules/m^2)

e - energy stored in electric field (joules)

H - distance from center of equivalent sphere to grounded wall for ESD calculations (m)

i_{in} charging current (amps)

k - dielectric coefficient (dimensionless)

l - separation distance for ESD calculations (m)

M - mass (Kg)

$\dot{m}$ - mass flux (kg/sec)

N - normal force for frictional heating (Newtons)

P - probability (dimensionless)

Q - heat of reaction per unit mass (cal/g)

Q - electrical charge for ESD calculations (coulombs)

R - gas constant (cal/mole°k)

R - electrical resistance (ohms)

R - equivalent radius of sphere for ESD calculations (m)

T_c- critical temperature below which conductive heat transfer is adequate to remove heat produced inside the body of explosive by exothermic reaction (°k)

T_o- boundary temperature in thermal explosion model (°k)

t - time (sec, min, or hr)

te - time to explosion (sec, min, or hr)

V - voltage (volts)

W - path width for surface resistance ESD estimates (m)

Z - pre-exponentrol factor (sec^{-1})

S - shape factor in thermal explosion model (0.88 for slabs, 2.00 for cylinders, and 3.32 for spheres)

ε_o - permittivity of free space $\left(8.85 \times 10^{-12} \dfrac{coul^2}{nt\text{-}m^2}\right)$

λ - thermal conductivity (cal/cm°k sec)

ρ - mass density (g/cc)

δ - surface resistivity (ohm)

τ - characteristic electrical relaxation time(sec)

Subscripts

max - maximum

in - input flux